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Research Council

AN AIR MASS BACK TRAJECTORY AND PRECIPITATION CHEMISTRY ANALYSIS WITHIN NORTHERN SASKATCHEWAN

by

S.R. Shewchuk

SRC Technical Report No. 173

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SUMMARY

Saskatchewan Environment has had in place an event rain chemistry network during the years 1983 and 1982. It is the purpose of this study to analyze and interpret the results of this network for these years. At the time of ending of precipitation a one day back trajectory was constructed to consider the influence of regional emissions on the rain chemistry. There were 73 and 37 air mass back trajectories analyzed for the years 1983 and 1982 respectively. It is seen that the rain quality at all sites was significantly influenced by the trajectories from the southern areas. These trajectories produced higher concentrations of most major inorganic ions in the rainfall. The influence of forest fires on the rain chemistry could be seen when analyzed with trajectories. In the presence of forest fires the acidity and nitrates within the rainfall were seen to increase.

The rain in Northern Saskatchewan can be considered a dilute solution of many different ions. Most of the rainfall samples are acidic. The source of acidity is unknown at present but it is likely not an inorganic mineral acid. Total annual wet deposition of sulphur was estimated to be in the order of 1 kg(S)/ha. The area is highly sensitive to acid deposition. By using aquatic system sensitivities it is suggested that even small increases in present deposition could begin acidification of the environment.

ACKNOWLEDGEMENT

This work was carried out under contract No. 34 (84-85) with Environment Saskatchewan. The author would like to sincerely thank Mr. L.J. Lechner of Environment Saskatchewan for providing the contract and for the many helpful discussions during the course of the research. The synoptic upper air and surface meteorology charts used in this study were provided by Mr. D.J. Bauer of Environment Canada. I would also like to acknowledge the assistance of Mr. Rolf Jahren, a Senior Research Technologist with the Saskatchewan Research Council, for providing contributions to collecting the forest fire data and analyzing the extent of forest fires on the precipitation quality. Mr. James Ross of the Saskatchewan Research Council provided technical assistance on graphics and general report presentation. The assistance of Liz Weegar and her staff of Stenographic Services of SRC is also gratefully acknowledged. This report was the first through the SRC word processing system. Special thanks are due to Sandra Mangatal for typing this report into the new format.

Finally the dedication of the field observers who collected the precipitation for Environment Saskatchewan is well worth noting. In a field intensive project such as this, maintaining a high quality data set requires a significant level of interest from field personnel. As shown in this report there has been a high level of attention paid to the collection of precipitation.

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1. INTRODUCTION

1.1 Natural Rainfall Acidity

During the past several decades scientific evidence has been collected which suggests that air pollution resulting from emissions of sulphur and nitrogen oxides may have significant adverse effects on ecosystems even when the pollutants or their reaction products are deposited from the atmosphere into locations remote from major sources of that pollution. A recent study has been conducted by Shewchuk et al., 1981 which indicates that there are areas within Saskatchewan that are highly sensitive to this deposition. Precipitation chemistry has been monitored by Saskatchewan Environment in the Northern part of this province for the years 1983 and 1982. It is the purpose of this study to analyze the results of this network from the point of view of air mass back trajectories and total atmospheric wet deposition rates to the environment. Preliminary estimates of wet deposition impacts are also to be addressed. Since most of Northern Saskatchewan is located within the Precambrian Shield, it is likely that the rain can be considered as a dilute solution of several inorganic ions (Shewchuk, 1982). While dilute natural rainwater pH is considered to be 5.6 (i.e. carbon dioxide is the main acidity control), there are many remote locations on the earth's surface where rainwater pH values are measured below 5.6. Several authors (Chameides et al., 1983, Keene et al., 1983, Shewchuk, 1983) have suggested that natural organic or trace levels of strong acids may be lowering the pH in remote areas. A recent paper by Keene et al., 1984 has shown that the mean pH of rainwater in southern Venezuela forests was in the order of 4.7. These authors speculate that this acidity may be caused by the volatilization of phosphorus and

sulphur from the forest into the atmosphere, where these elements are oxidized to phosphate and sulphate ions and returned to the environment as phosphoric and sulphuric acids. Ion balances based on major inorganic species collected from remote areas of the world revealed consistent anion deficits at certain sites. The authors have suggested that this was evidence that organic acids were contributing to the free acidity. Several preliminary studies have shown the presence of organic acid anions including formic acid and acetic acids. There are many theories of natural acid rain formation but whatever the cause, natural acid rains with pH values less than 5.6 are well documented.

1.2 Regional Acid Deposition with Trajectory Interpretation

In industrial regions it is possible to identify much of the chemical major ion species being deposited as those associated with strong mineral acids. Strong acids present in the deposited rainfall can significantly dominate the solution chemistry. Wet deposition through rainfall is a particularly efficient manner in which to deposit sulphur to the environment as an acid. Within a 50 km radius of a major metal smelter located at Sudbury, Ontario, Chan et al., 1982 found that the relative contribution of the emissions to the total deposition of acids was in the order of 10-20%. In addition the rate of scavenging of acids depends quite significantly on the type of weather systems passing through the area. It was found that there was an influence of the smelter plume on the local downwind quality of the precipitation.

It is possible to document the origin of the air mass aerosol structure with back trajectories. This is a method of relating the regional emissions (whether they be natural or anthropogenic) to the

observed value of the precipitation chemistry. There have been several air mass trajectory studies conducted to show the usefulness of this analysis in the interpretation of acid deposition periods. A recent air mass trajectory study was performed, (Kurtz, et al., 1984) on an acidic deposition episode which occurred at Dorset in the Muskoka-Haliburton Highlands of Ontario in 1981. The wet-deposited sulphate during this period accounted for 28% of the total annual acid. This trajectory study implicated directly air pollution sources south and southwest of the study region. Air pollution tends to be advected by regional air masses. Thus it becomes mixed with the air mass and it is influenced by the dynamic processes occurring, i.e., convective activity within the air mass.

1.3 Forest Fires as a Source of Air Pollution

A natural source of air pollution for the area of Northern Saskatchewan is the occurrence of forest fires. These fires release vast quantities of pollutant aerosols which make their way into the chemistry of the downwind precipitation. Studies have shown that forest fires have often been known to significantly effect the quality of precipitation. Airborne measurements of cloud condensation nuclei were made in the vicinity of a burn of natural forest fires (Eagan et al., 1974). The concentration of active nucleii (i.e. capable of forming cloud droplets) reached 5000 per cubic centimetre at about 38 km downwind of the fire, compared to concentrations in the range of 250-500 per cubic centimeter upwind. According to Radke et al., 1978 forest fires are a significant source of nitrogen dioxide. These oxides can be quickly oxidized within the atmosphere to nitric acid and deposit as acid.

1.4 Mesoscale Meteorology

In the regional interpretation of air pollution the meteorology of medium range transport has been known to significantly redistribute the pollutant impacts (Blondin, 1984). Atmospheric dynamics play an important part in the transfer and turbulent diffusion of pollutants. Trajectories are a particularly simple method of classification of the impacts. The Atmospheric Environment Service has applied a mesoscale model to the area of western Canada (Kociuba et al., 1984). Estimates of wet deposition of sulphate in the Cree Lake area of Saskatchewan was 1.25 kg(S)/ha per year. The background component contribution to this annual value was given as approximately 75%. The authors have suggested that the model seems to underestimate the actual amount of deposition. This is the case because ambient levels of most traces gases (SO_2, NO_x etc.) are below detection with standard methods. There were however many data gaps in the precipitation chemistry field which made most comparisons uncertain. It was interesting to note that, at remote sites within western Canada, the wet deposition of sulphur dominated the total sulphur deposition.

In this study the construction of precipitation back trajectories will be considered in the interpretation of event precipitation impacts. The geostrophic wind was calculated on the surface synoptic charts by a method outlined by Petterssen (1956), using an advection scale whereby the gradient of the isobaric field can be considered directly proportional to the magnitude of the wind. The direction of the wind was taken to be that of the streamlines defined by the isobaric surface. The geostrophic wind was considered typical of the wind speed and direction at the top of the Planetary Boundary Layer (PBL) or mixed

layer. Atmospheric motions are very complex and not simple to quantify. Trajectories are only a first estimate of wind flow patterns. They are to be used in this study for interpretation purposes.

The troposphere is made up of several air masses. Air masses are characterized by their source regions. For example, a continental air mass has a source region of the continents and is usually dry and cool. Maritime air mass has a source region over the oceans and is characterized by warm moist conditions. Fronts separate the air masses. The most important cooling process for precipitation formation is the adiabatic expansion associated with rising air. The lifting processes for the air masses are topography, fronts, convection, mechanical turbulence and convergence. At a front the colder air often acts as an "inclined plane" that forces the warmer air to rise. Therefore considerable precipitation may develop. Cold air advances at cold fronts and retreats at warm fronts. In a cyclonic vortex (low pressure system) it is possible to have an advancing cold front cut the warm air completely off from the ground. The warm air becomes occluded and is trapped as a trough of warm air aloft, formed by the sides of the advancing and retreating portions of the cold air mass. Precipitation cloud systems are often found in this trough system. Because of the uplift generated by a cold front, showers and thunderstorms can often accompany this type of front. They are often abrupt in nature. Warm fronts give a wider variety of weather. They give extensive areas of cloud and precipitation. For example, moist stable overrunning warm air will produce an extensive area of layer clouds with light to moderate continuous precipitation. Precipitation at a trowal (trough of warm air aloft) is a

combination of both cold front and warm front precipitation and depends on the atmospheric dynamics of the weather systems for support.

For purposes of interpretation in this study, it was assumed that air pollutants were emitted into the atmosphere, then were mixed more or less uniformly in the vertical by the weather systems. During the formation of precipitation this uniformly mixed polluted atmosphere acts as a primary inflow that supports the dynamics of precipitation systems. These precipitation systems scavenge, or remove by some other process, the pollutants from the atmosphere.

1.5 Sensitivities

Aquatic systems become acidified due to the lack of alkalinity. Accordingly, Liaw and Atton (1981) considered the alkalinity structure of Northern Saskatchewan lakes. Fifty-four percent of Provincial water bodies, including Cree, Wollaston, Athabasca and Reindeer Lakes, were involved in their study. These lakes were found to be highly sensitive to acid deposition. In this study a preliminary assessment of deposition rates of acid to the study area was made. An attempt was also made to determine how many years it would take to acidify many of the smaller lake systems within this area, based on these deposition rates.

2. MATERIAL AND METHODS

2.1 Collection and Chemical Analysis

This project involves the analyses and interpretation of rain chemistry data collected at several sites in Northern Saskatchewan during the years 1983 and 1982. All the sites used during the study period are shown in Figure 2.1. The rainfall at each site was collected on an event basis. An event was defined as beginning at the start of the rainfall and concluding at its end. Once rainfall had occurred the sample was frozen and later transported to the analytical laboratory of the Saskatchewan Research Council for analysis. Freezer facilities were not available at all sites, so best attempts were made to keep the samples as cool as possible.

The collection procedures and samplers used are described in Appendix A. The sample collector is shown in Figure 2.2. A large plastic container was lined with a polyethylene bag (prewashed) that could be easily sealed in the field to avoid handling contamination. Several tests conducted by Chan et al., 1983 have shown that polyethylene surfaces were quite good collection media for rain which was to be analyzed for major inorganic ion constituents. The tests showed no significant adsorption of hydrogen ion, sulphate, nitrate, ammonia, chloride, calcium, magnesium, and sodium. The container was normally sited according to MacQuarker et al., (1982) away from local sources of emission and contamination. The container and the plastic bag liner were sealed with a tight fitting lid. At the time of rainfall the lid was opened and the plastic bag filled up with rainwater. Then the plastic bag sample was sealed, indexed and stored for shipment. The amount of rainfall during each event was measured with a standard wedge gauge. Samples at each

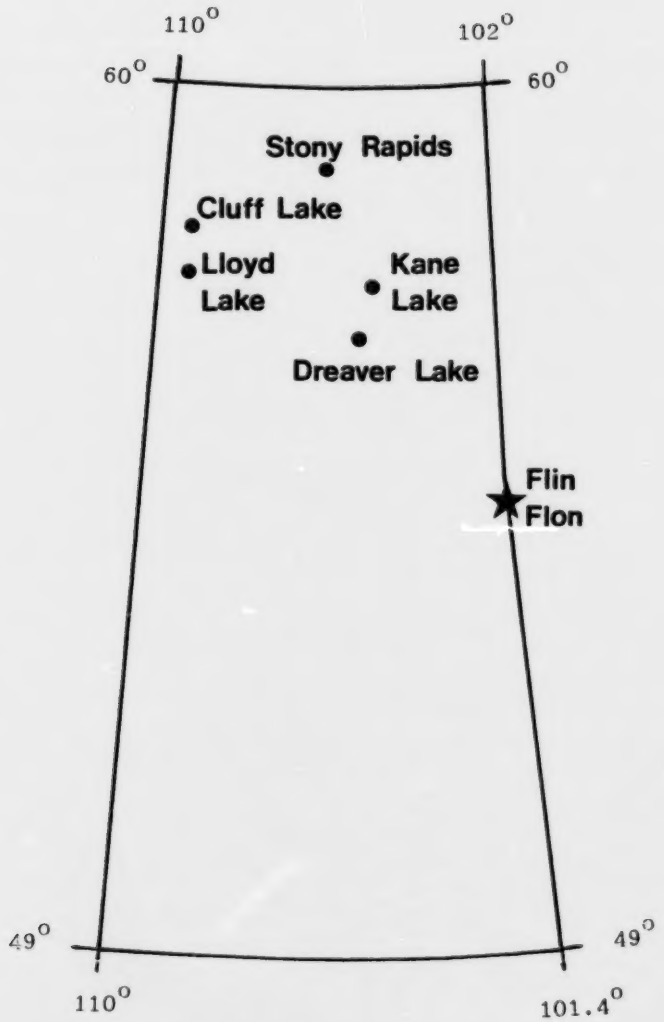


Figure 2.1. The location of the rain collection sites for 1983 and 1982 from the Saskatchewan Environment network.

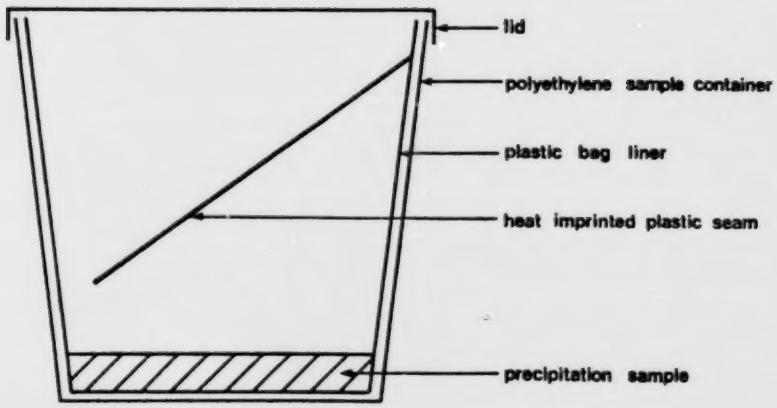


Figure 2.2. The Saskatchewan Environment wet deposition collector.

site were normally kept for most of the observation period in the field then sent to the laboratory for analysis at the end of the season.

Once in the laboratory a major inorganic ion balance was conducted on each sample. Sulphates and chlorides were determined with an ion chromatograph to a detection limit of <0.05 milligrams per litre (mg/L). The pH was determined by electrode measurements and by Gran titration, when sample volume permitted. Titration allowed separation of strong and weak acidity components in the solution. Nitrates were determined by colorimetric procedures to a level of <0.05 mg/L. Ammonium was determined by titration procedures to <0.01 mg(N)/L. Most metals such as calcium, magnesium, potassium and sodium were determined by atomic absorption spectrometry. Trace metals were determined by ICP-AES analysis (plasma emission spectrometry).

A main thrust of this project was to determine the regional distribution of the major ion components of the rain. Special importance was given to sulphate, nitrate and hydrogen ion as they are considered of prime concern in the acidic deposition structure.

2.2 Synoptic Meteorology Analysis

Surface and upper air synoptic charts (scale 1:10,000,000) were obtained from the Saskatoon weather office of Environment Canada for the field observation periods during 1983 and 1982. The surface synoptic map generated by the Winnipeg Weather Central, was used for the study. One day back trajectories were drawn for each rain collection site in Northern Saskatchewan starting at the time the precipitation ended.

The back trajectories extend back in time to a period of twenty-four hours. Thus four 6 hour periods were used to make up each trajectory. The trajectory start time was always the nearest synoptic hour to the ending of the precipitation. The surface geostrophic wind was considered to be equal to the wind speed and direction at the top of the mixing layer. Each time a trajectory was drawn the general overall dynamic meteorological features that were influencing the precipitation development were noted. Such concepts as the location and movements of the cyclonic systems in the area, the location of troughs, whether the low was occluding or not and where the upper level trowal was located were also noted. All of these meteorological concepts can have a significant effect on the development, the quality and type of precipitation. General synoptic features are important because they can play a major part in the development of an ascending air mass structure from which precipitation is formed.

The trajectories were drawn for each rainfall event and classified according to direction. Trajectories that lay in a sector north of the site were separated from those that lay south of the site etc., and the ion chemistry was documented.

Forest fires occur quite regularly over vast areas of Northern Saskatchewan. Therefore the contribution of forest fires to regional pollution contamination was addressed. The occurrences of forest fires in the provinces of Alberta, Manitoba and Saskatchewan were considered. All fires 100 hectares and larger were charted on a map.

A band extending 100 km to each side of the trajectory and running its full length was assumed to be the area of influence. This area was examined for fire occurrences and the concentration of various ion

species found in the rain samples was tabulated, by site, into those having "no fire occurrence" and those having one or more "fire occurrences" burning concurrent with the rainfall. The parameters examined were pH, sulphate, nitrate, and calcium.

2.3 Regional Wet Deposition

Wet deposition was calculated for the study period by integrating the effects of each individual event for the sulphate, nitrate and calcium ions. Deposition refers to the total flux of a particular species to the ground surface. Each individual rainfall event would contribute a separate component to this flux. The total deposition is the sum of all the events. The annual total wet deposition for several of the sites was calculated by using the data collected from previous studies in the area and annual rainfall data collected by Environment Canada.

2.4 Ion Balances on the Rainfall

The importance of each individual constituent within the precipitation can be assessed with an ion balance. A major ion balance was conducted on all of the samples to make sure all of the ions were accounted for. The major constituents of the ion balance also determine the particular ionic species that is controlling the quality of the solution. For example, an ion balance can be used in an acid precipitation solution to identify the major acid contributing to the solution acidity. If the hydrogen ion (acidity) is originating from sulphuric acid then the sulphate ion should be readily identified. Organic ions (acetic, formic, citric ions etc.) were not determined in this project,

therefore any organic acid will show up as an excess hydrogen ion in the solution with no corresponding anion.

2.5 A Sensitivity Approach to Lakes

By using a simple nomograph structure as developed by Liaw (1981) it is possible to obtain an understanding of the impact of various deposition rates onto the aquatic systems in this area. Approximate calculations can be made to determine how long it would take to provide acidification of the environment given a series of assumptions. A typical small lake system on the Precambrian Shield of Saskatchewan was considered.

3. RESULTS

3.1 Trajectory Analysis

The number of trajectories analyzed for each site during the two years of operation is given in Table 3.1.

Table 3.1. Number of Trajectories Analyzed for the Rain Events

a) 1983 Site	Number
Lloyd Lake	8
Stony Rapids	2
Cluff Lake	5
Dreaver Lake	38
Kane Lake	20

b) 1982 Site	Number
Cluff Lake	7
Dreaver Lake	19
Kane Lake	8
Stony Rapids	3

The results of the meteorological trajectory studies are shown only in part in Figures 3.1 to 3.13 for the 1983 field year and Figures 3.14 to 3.19 for the 1982 field year. While there were 73 analyses for 1983, only 12 are shown to illustrate typical situations. For each of the sites the trajectories from various quadrants shown were thought typical of the data set. Along with the trajectory was given the initiation time in Greenwich Mean Time (G.M.T.-Z) and a description of the synoptic meteorology. The amount of rainfall and its analytical chemistry is given in the legend. Figure 3.1 shows a trajectory moving from the south into Dreaver Lake. The precipitation is orginating from a weak

low system that is slowly moving to the east. The trajectory passed near the industrial complex at Flin Flon. The value of sulphates are thought typically quite high for the region with the acidity being at 4.92. The air originates mostly over the Precambrian Shield areas of Saskatchewan and Manitoba. Figure 3.2 is an illustration of the synoptic meteorology patterns at the time of ending of precipitation at Dreaver Lake, during the event indicated in the previous figure. The geostrophic wind flow is parallel to the isobars and is in a counterclockwise direction about the low system. The precipitation at Dreaver Lake was the result of this system moving into the region. The fact that the circulation centre was southeast of the site indicates that the mixing layer winds were influenced by air from southeast of Dreaver Lake. In Figure 3.3 a weak troughing structure results in precipitation at Dreaver Lake with quite high levels of sulphate and acidity. A trajectory into Dreaver Lake from the south is shown in Figure 3.4. Here the rain was caused by a broad scale trough running directly along the western boarder of this province. The rain trajectories from the southern area are seen to be less acid as the air originates from the farm land in the south. A northwesterly trajectory into Dreaver Lake is shown in Figure 3.5. A deep cyclonic system was off to the northwest. It was associated with a frontal structure as shown. It was this structure that resulted in the precipitation. The rain pH structure was considered slightly acidic at 5.72.

A rain trajectory into Kane Lake from the northwest is shown in Figure 3.6. The rain resulted from an upper level trough that was associated with a deep cyclone. All major ion species of the rainwater

Date	05/17/83
Rainfall, mm	3.5
Ca, mg/L	0.36
Cl, mg/L	1.3
K, mg/L	0.6
Mg, mg/L	<0.05
Na, mg/L	0.26
SO_4, mg/L	3.0
N, (NH_3) mg/L	<0.01
NO_3, mg/L	0.073
Acidity Strong, meq/L	0.018
Acidity Weak, meq/L	0.021
pH	4.92

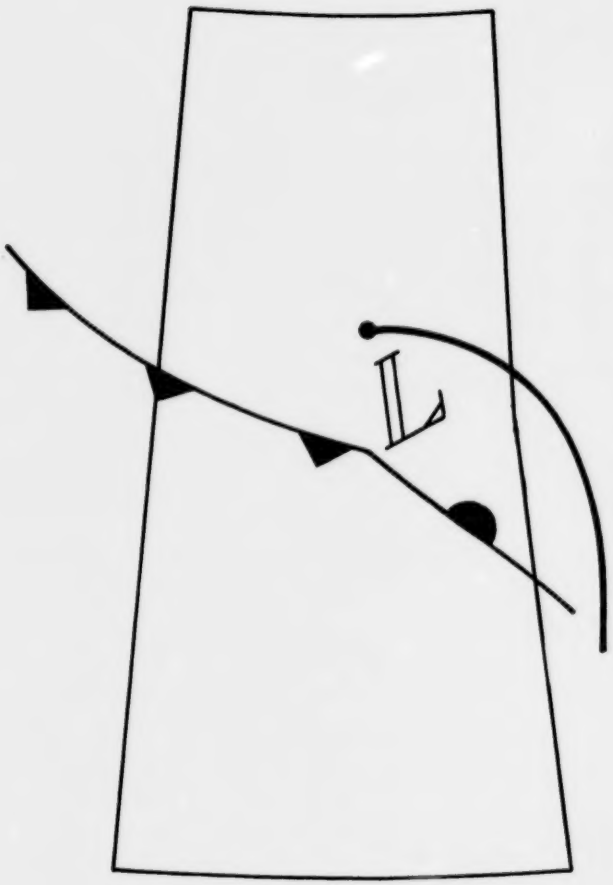


Figure 3.1. Trajectory moving into the Dreaver Lake site from the southeast. Trajectory initiation time was 5/18/12Z.

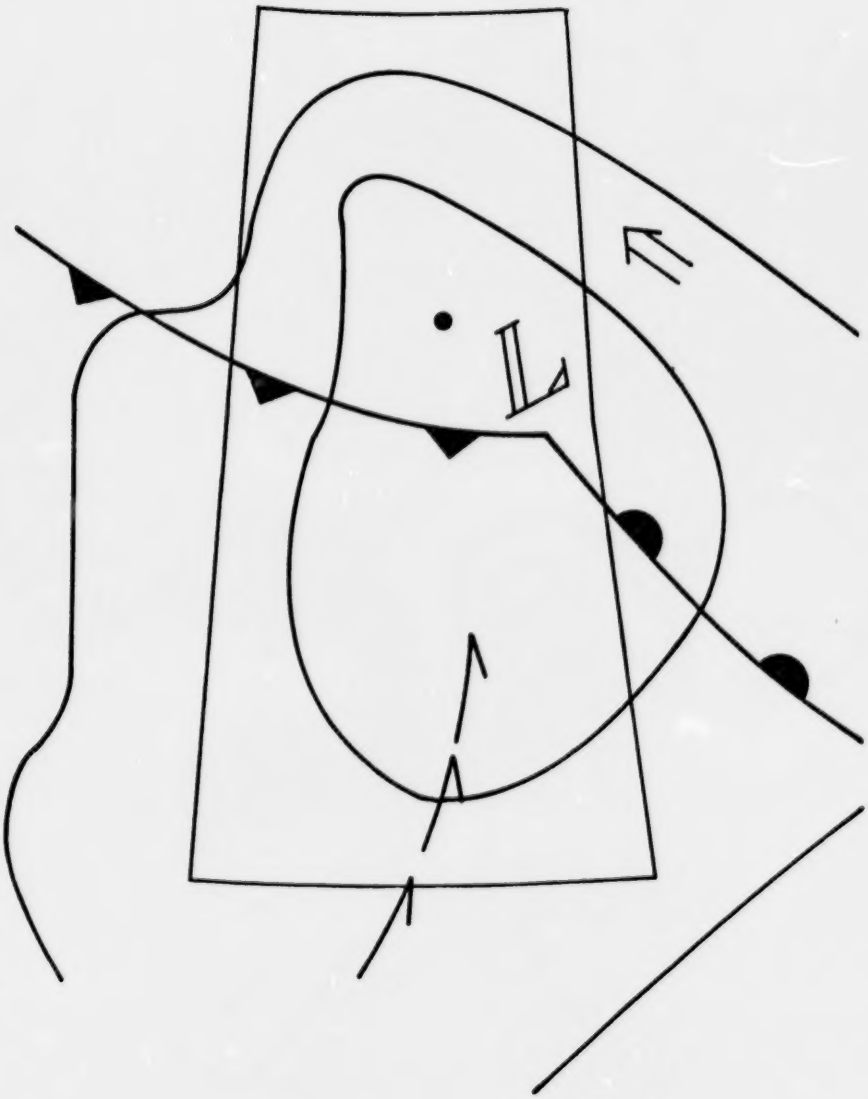


Figure 3.2. The synoptic meteorology occurring (1983) for the trajectory initiation time of 5/18/12Z.

Date	05/18/83
Rainfall, mm	1.2
Ca, mg/L	0.89
Cl, mg/L	1.4
K, mg/L	0.4
Mg, mg/L	0.07
Na, mg/L	0.02
SO_4, mg/L	6.0
N, (NH_3) mg/L	0.16
NO_3, mg/L	0.035
Acidity Strong, meq/L	0.013
Acidity Weak, meq/L	0.009
pH	4.88

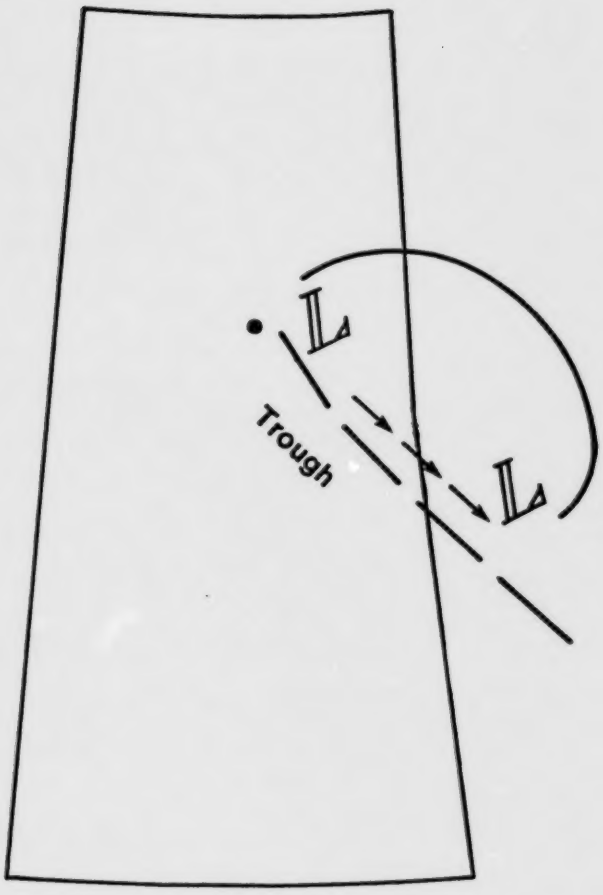


Figure 3.3 Trajectory moving into Dreaver Lake from the northeast. The rain resulted from a troughing structure. Trajectory initiation time was 5/18/18Z.

Date	05/25-26/83
Rainfall, mm	8.0
Ca, mg/L	0.24
Cl, mg/L	0.19
K, mg/L	<0.2
Mg, mg/L	<0.05
Na, mg/L	0.02
SO_4, mg/L	0.20
N, (NH_3) mg/L	0.17
NO_3, mg/L	0.34
Acidity Strong, meq/L	NA
Acidity Weak, meq/L	0.022
pH	6.10

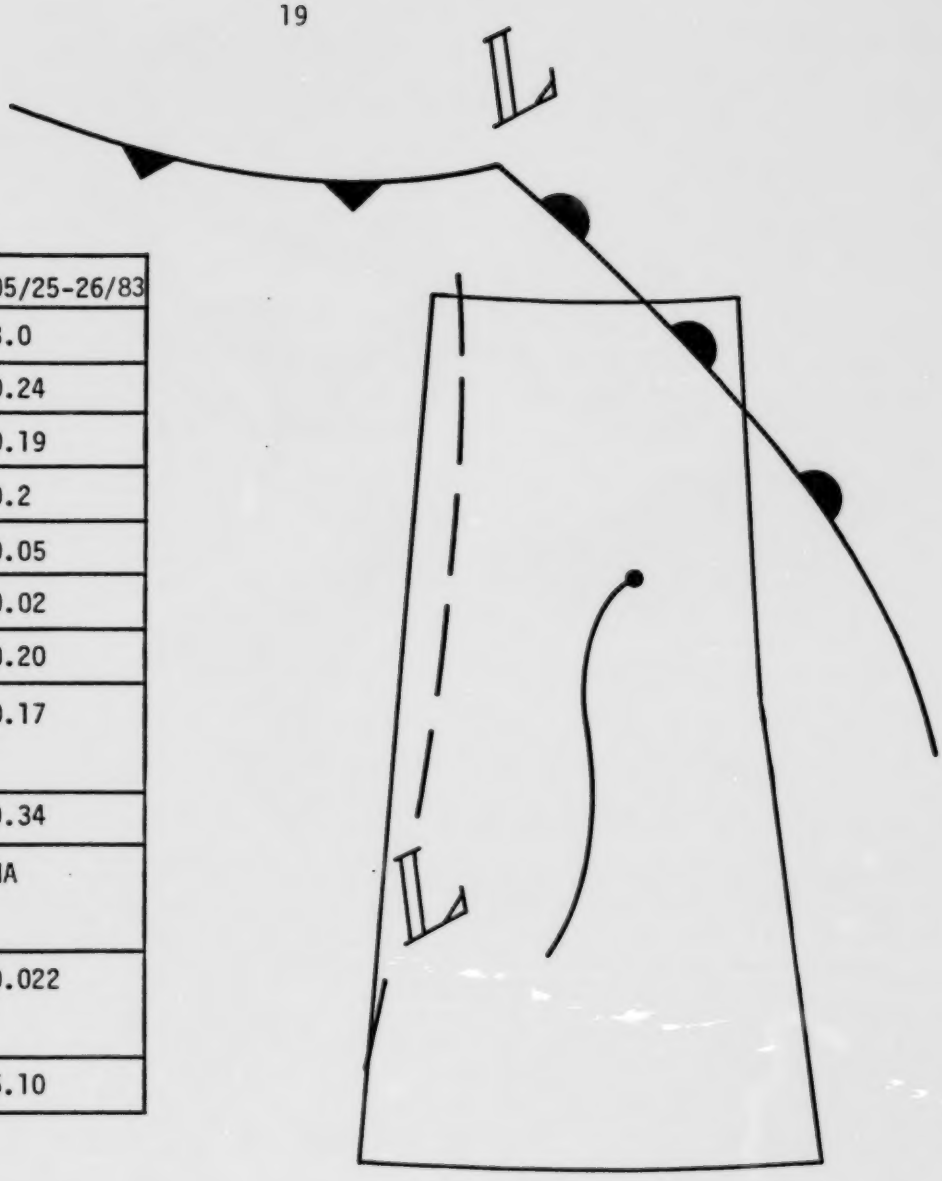
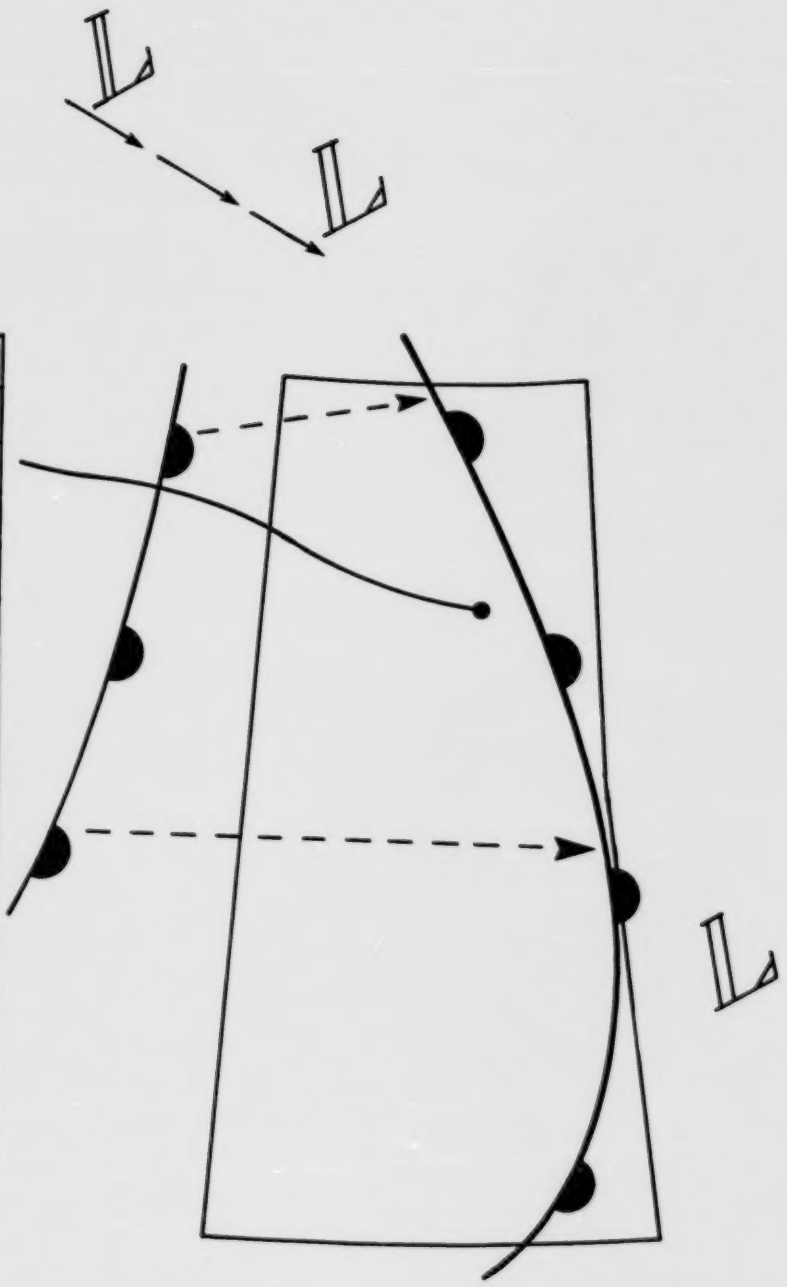


Figure 3.4 A trajectory moving from the south into Dreaver Lake. A stable weak troughing structure on the western boundary of the province provided the uplift. Trajectory initiation time was 5/26/12Z.



Date	06/07/83
Rainfall, mm	7.0
Ca, mg/L	0.16
Cl, mg/L	0.18
K, mg/L	0.3
Mg, mg/L	<0.05
Na, mg/L	0.06
SO_4, mg/L	0.22
N, (NH_3) mg/L	0.068
NO_3, mg/L	0.052
Acidity Strong, meq/L	0.010
Acidity Weak, meq/L	0.011
pH	5.72

Figure 3.5 A northwesterly trajectory at Dreaver Lake. Rain resulted from a rapidly moving front through the area. The trajectory initiation time was 6/07/18Z.

Date	06/07/83
Rainfall, mm	5.0
Ca, mg/L	0.22
Cl, mg/L	0.033
K, mg/L	<0.2
Mg, mg/L	<0.05
Na, mg/L	0.08
SO_4, mg/L	0.46
N, (NH_3) mg/L	0.14
NO_3, mg/L	0.077
Acidity Strong, meq/L	0.015
Acidity Weak, meq/L	0.006
pH	5.85

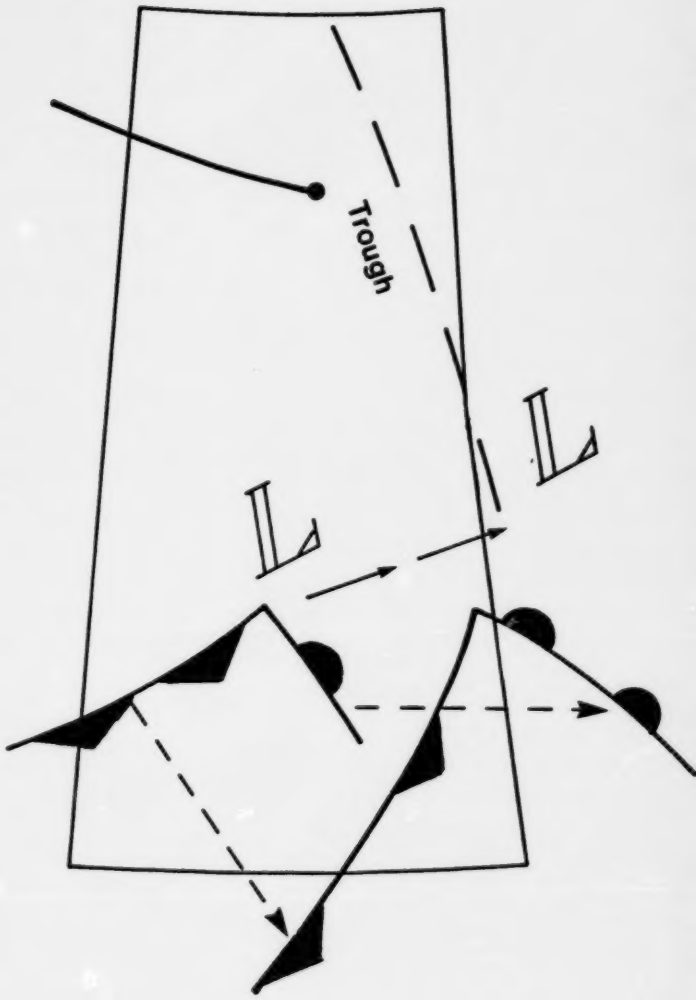


Figure 3.6 A northwest trajectory at Kane Lake originated from a deep low system in the southern part of the province and it was associated with a trough. The trajectory initiation time was 6/8/00Z.

tended to be quite dilute. An intensive low pressure area over the Hudson Bay area resulted in the trajectory from the northeast at Kane Lake in Figure 3.7. The precipitation from this northerly quadrant can be considered acidic. Figure 3.8 shows a deep low system moving through the area to the northwest of the Kane Lake site. Precipitation resulted from the troughing structure off to the west. This trajectory while it appears to be from the south, has actually had a curvature from a southerly to a northerly direction passing over the central to northern portions (Oil Sands Area) of Alberta. The acidity values and major ions were elevated for most ion species. Finally at Kane Lake, Figure 3.9 shows a trajectory originating in the southeastern area. The precipitation resulted from a cyclonic circulation system passing south of the site. The trajectory was part of the return circulation about this system. The acidity values can be considered quite high. Total acidity was 60 microequivalents per litre.

A 1983 Lloyd Lake trajectory from the north is shown in Figure 3.10. Precipitation resulted from a slow moving weak cyclonic system off to the northeast. The precipitation was of frontal origin. Most chemistry parameters were quite dilute with a pH value of 6.16. A trajectory from the south into the Lloyd Lake site is seen in Figure 3.11. A weak troughing structure to the southeast resulted in the precipitation which can be classified as mildly acidic.

Figure 3.12 shows a trajectory from the southeast entering the Stony Rapids site, with an acidity value of 5.75. At Cluff Lake in Figure 3.13 a trajectory was entering the site from the north with an acidity value of 5.26. The Cluff Lake trajectory in this case was more

Date	06/14/83
Rainfall, mm	22.0
Ca, mg/L	0.10
Cl, mg/L	0.036
K, mg/L	<0.2
Mg, mg/L	<0.05
Na, mg/L	0.04
SO_4, mg/L	0.24
N, (NH_3) mg/L	0.035
NO_3, mg/L	0.043
Acidity Strong, meq/L	0.011
Acidity Weak, meq/L	0.019
pH	5.08

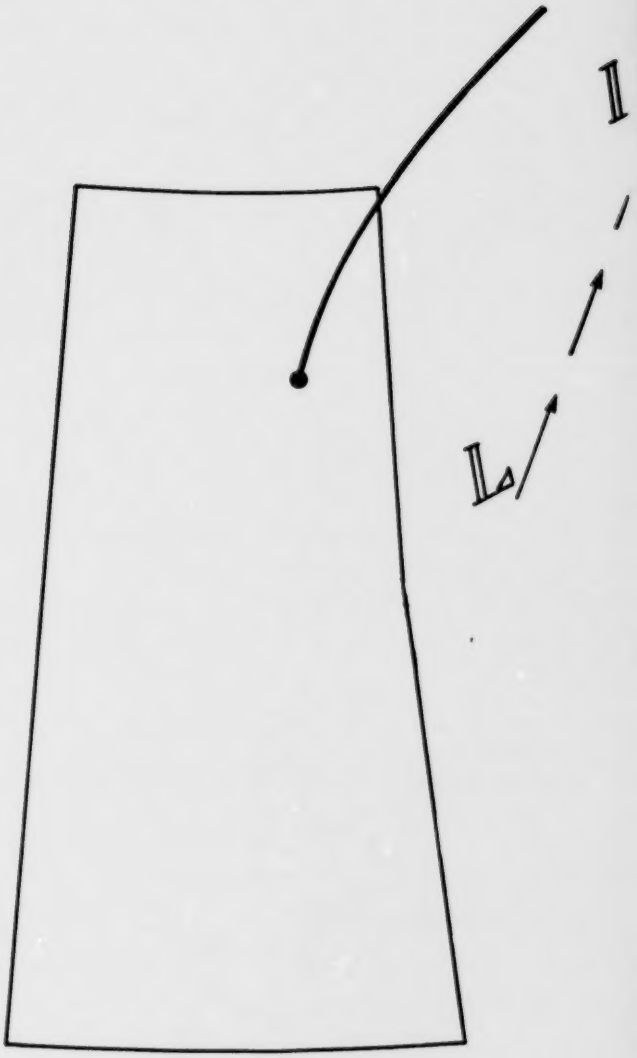


Figure 3.7 A northeast trajectory at Kane Lake originated from an intense low system over Hudson Bay. Trajectory initiation time was 6/14/18Z.

Date	07/15/83
Rainfall, mm	5.0
Ca, mg/L	0.34
Cl, mg/L	2.7
K, mg/L	<0.2
Mg, mg/L	0.06
Na, mg/L	<0.02
SO_4, mg/L	0.80
N, (NH_3) mg/L	0.10
NO_3, mg/L	0.10
Acidity Strong, meq/L	0.033
Acidity Weak, meq/L	0.030
pH	4.42

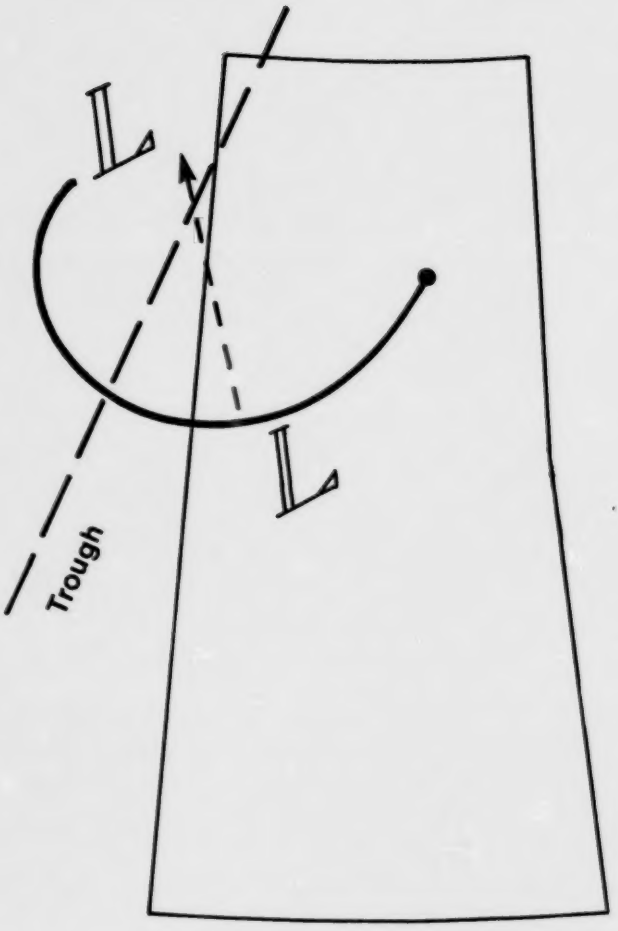


Figure 3.8 Deep low system was moving through the area northwest of the Kane Lake site. Precipitation resulted from the troughing structure. Trajectory initiation time was 7/15/18Z.

Date	08/03/83
Rainfall, mm	22.5
Ca, mg/L	0.13
Cl, mg/L	0.02
K, mg/L	0.30
Mg, mg/L	<0.05
Na, mg/L	0.11
SO_4, mg/L	0.42
N, (NH_3) mg/L	0.12
NO_3, mg/L	0.080
Acidity Strong, meq/L	0.037
Acidity Weak, meq/L	0.023
pH	4.56

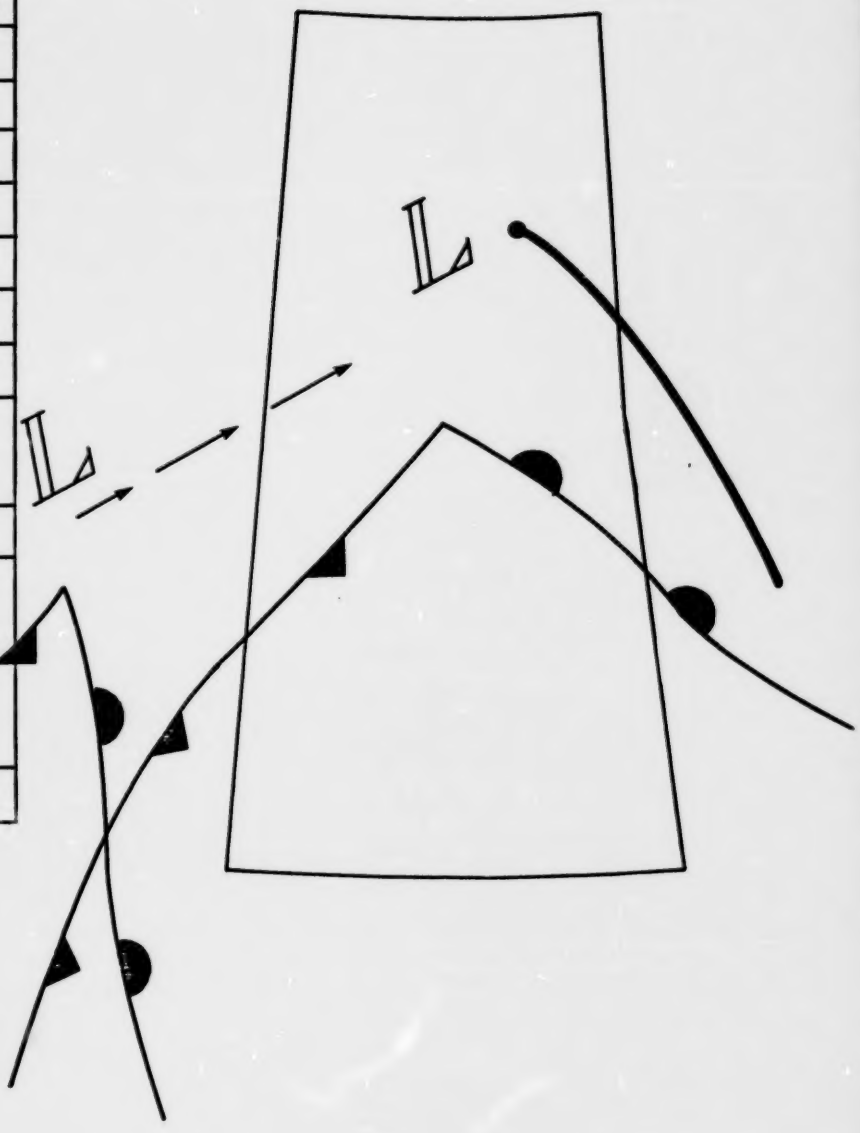


Figure 3.9 A southeasterly trajectory moving into Kane Lake resulted from a moderately moving low system to the southwest. Trajectory initiation time was 8/4/00Z.

Date	08/18/83
Rainfall, mm	5
Ca, mg/L	0.21
Cl, mg/L	0.15
K, mg/L	<0.2
Mg, mg/L	0.06
Na, mg/L	<0.02
SO_4, mg/L	0.14
N, (NH_3) mg/L	<0.01
NO_3, mg/L	0.017
Acidity Strong, meq/L	NA
Acidity Weak, meq/L	0.003
pH	6.16

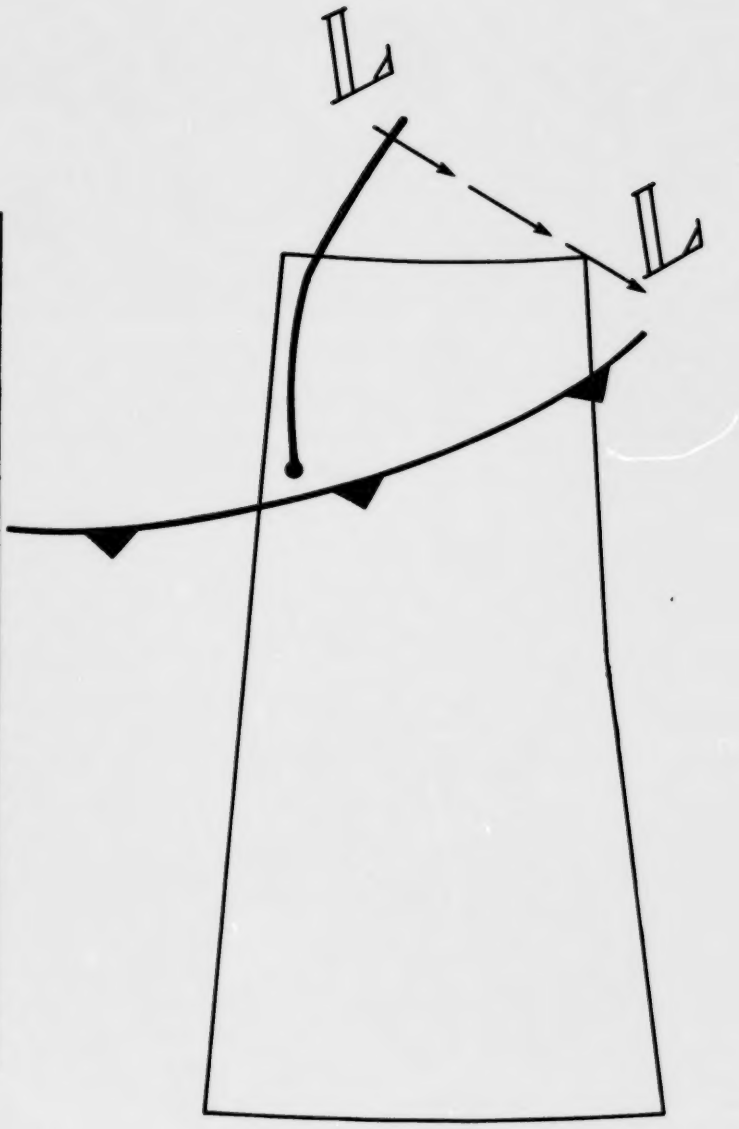


Figure 3.10. A northerly trajectory to the Lloyd Lake area 1983. There was a weak low system off to the northeast. The trajectory initiation time was 8/18/12Z.

Date	06/28/83
Rainfall, mm	12
Ca, mg/L	0.6
Cl, mg/L	0.053
K, mg/L	<0.2
Mg, mg/L	0.05
Na, mg/L	0.08
SO_4, mg/L	1.1
N, (NH_3) mg/L	0.13
NO_3, mg/L	0.29
Acidity Strong, meq/L	0.010
Acidity Weak, meq/L	0.020
pH	5.35

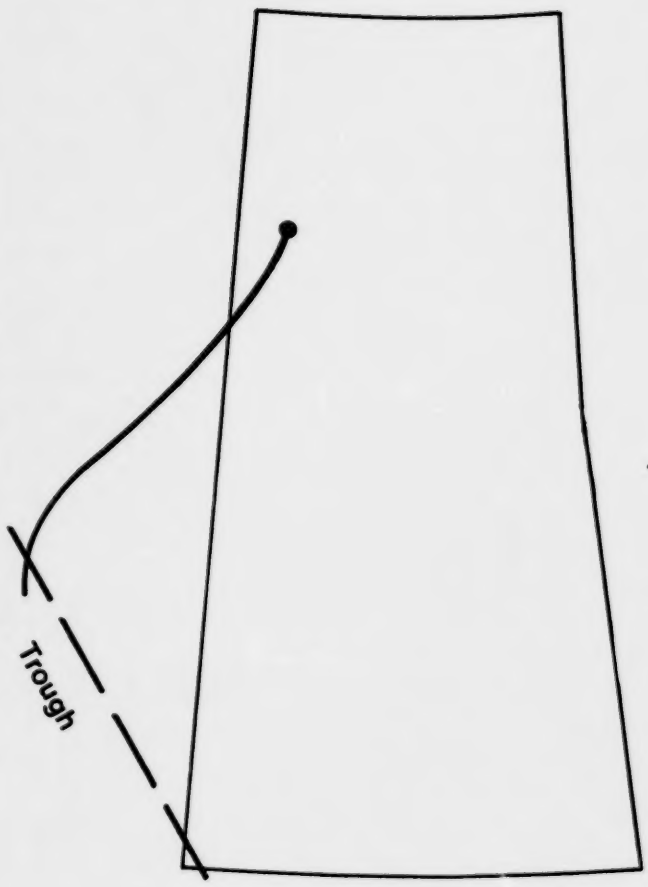


Figure 3.11 A trajectory from the south moved into the Lloyd Lake site. Precipitation resulted from a troughing structure to the southwest. The trajectory was initiated at 6/28/00Z.

Date	09/15/83
Rainfall, mm	3
Ca, mg/L	0.40
Cl, mg/L	0.26
K, mg/L	<0.2
Mg, mg/L	0.08
Na, mg/L	<0.02
SO_4, mg/L	0.87
N, (NH_3) mg/L	0.20
NO_3, mg/L	0.13
Acidity Strong, meq/L	0.005
Acidity Weak, meq/L	0.002
pH	5.75

Figure 3.12 A deep well-organized low in the MacKenzie Valley resulted in this southward trajectory to Stony Rapids. The trajectory initiation time was 9/15/18Z.

dilute than the Stony Rapids trajectory. This again illustrates the more dilute nature of the northerly air flows.

The trajectories illustrated from the 1982 results are shown in Figures 3.14 to 3.19. A trajectory from the south at the Dreaver Lake site is shown in Figure 3.14. The pH value of this event was 5.66 with a sulphate concentration of 0.72 mg/L. A trajectory from the north to Dreaver Lake during the rain is shown in Figure 3.15. The rain likely resulted from the troughing structure and was quite dilute with a pH value of 6.8. There is a significant increase in sulphate between the south and north trajectories. At Kane Lake for 1982 Figures 3.16 and 3.17 show a north and a south trajectory respectively. It can be seen from the major ion balance that the rain was quite dilute. The pH values were 4.45 and 5.14 respectively. A northerly trajectory for Cluff Lake is shown in Figure 3.18. The precipitation once again, while being dilute, was showing major amounts of acidity. Finally for Stony Rapids a south trajectory shows (Figure 3.19) an acid influence at 4.94 with virtually no detectable sulphate (<0.05 mg/L). The precipitation was due to a frontal system with an associated weak pressure system located to the west of the site. Mineral acids of sulphur and nitrogen cannot account for the acidity of these samples.

Date	08/18/83
Rainfall, mm	15
Ca, mg/L	0.08
Cl, mg/L	0.16
K, mg/L	<0.2
Mg, mg/L	<0.05
Na, mg/L	<0.02
SO_4, mg/L	0.10
N, (NH_3) mg/L	<0.01
NO_3, mg/L	0.028
Acidity Strong, meq/L	0.004
Acidity Weak, meq/L	0.002
pH	5.26

Figure 3.13 A front located just south of Cluff Lake caused a trajectory to move from the north into the site. Trajectory initiation time was 8/19/06Z.

Date	08/11/82
Rainfall, mm	11.0
Ca, mg/L	0.24
Cl, mg/L	0.05
K, mg/L	<0.2
Mg, mg/L	0.24
Na, mg/L	0.05
SO_4, mg/L	0.72
N, (NH_3) mg/L	0.05
NO_3, mg/L	0.22
Acidity Strong, meq/L	0.008
Acidity Weak, meq/L	0.016
pH	5.66

Figure 3.14 At the Dreaver Lake site there was a strong flow from the south due to a low located to the northwest and a front running directly north to south. The trajectory initiation time was 8/11/18Z.

Date	9/12/82
Rainfall, mm	1.0
Ca, mg/L	0.56
Cl, mg/L	0.07
K, mg/L	<0.20
Mg, mg/L	<0.05
Na, mg/L	0.2
SO_4, mg/L	0.18
N, (NH_3) mg/L	NA
NO_3, mg/L	NA
Acidity Strong, meq/L	NA
Acidity Weak, meq/L	NA
pH	6.78

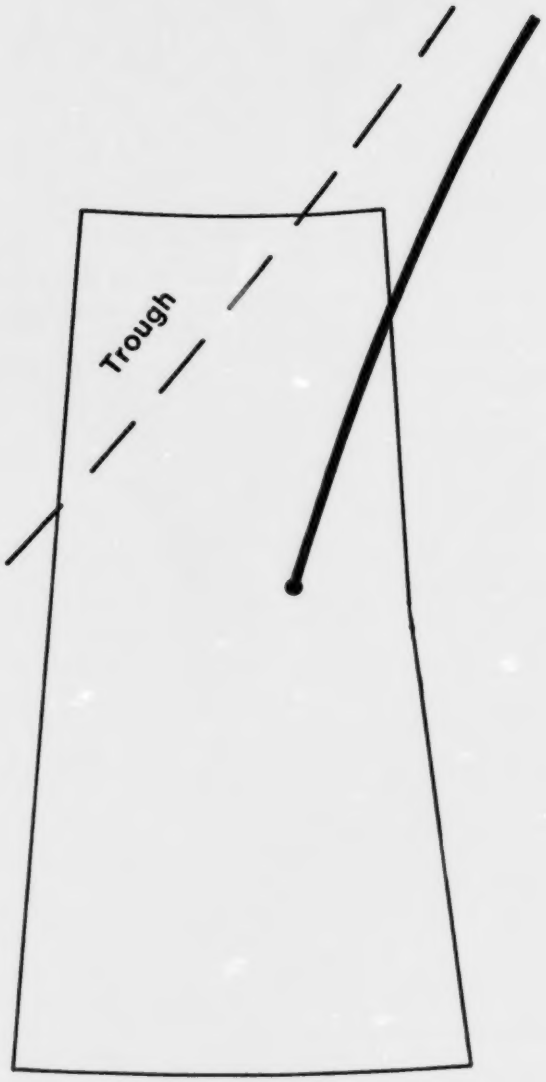


Figure 3.15 A strong northerly flow brings this trajectory into the Dreaver site. Rain resulted from the troughing structure as it passes the site. Trajectory initiation time was 9/13/00Z.

Date	7/28/82
Rainfall, mm	8.0
Ca, mg/L	0.17
Cl, mg/L	0.08
K, mg/L	<0.20
Mg, mg/L	<0.05
Na, mg/L	0.22
SO_4, mg/L	0.23
N, (NH_3) mg/L	0.35
NO_3, mg/L	0.44
Acidity Strong, meq/L	0.069
Acidity Weak, meq/L	0.029
pH	4.45

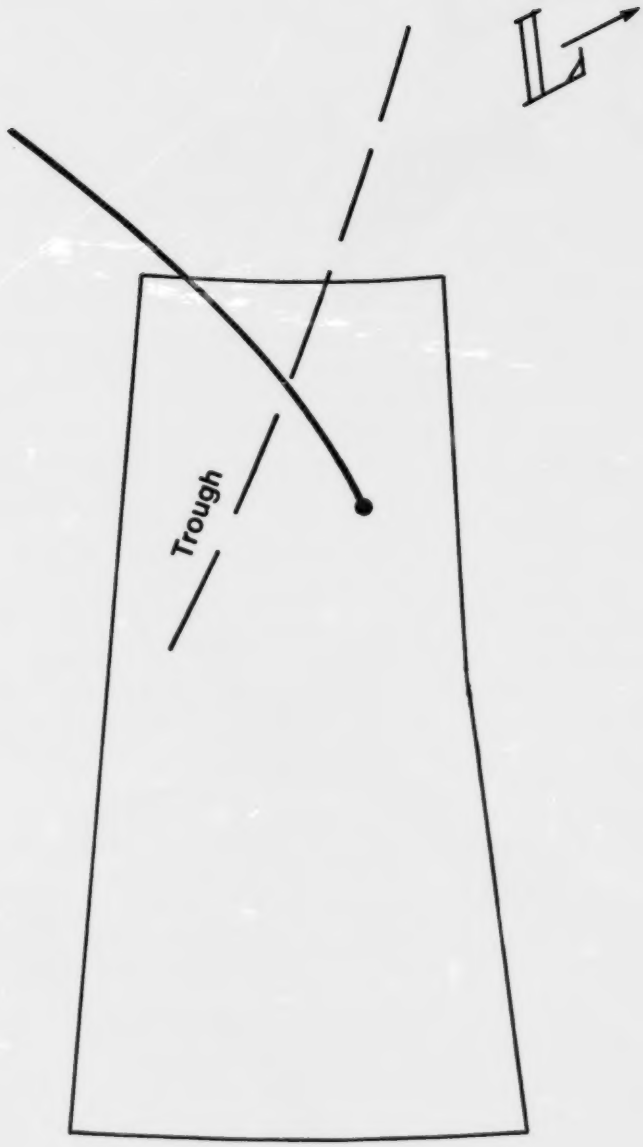


Figure 3.16 A weak low to the northeast and its associated trough resulted in this trajectory from the northwest to the Kane Lake site. Trajectory initiation time was 7/28/18Z.

Date	8/03/82
Rainfall, mm	9.0
Ca, mg/L	0.18
Cl, mg/L	0.11
K, mg/L	<0.20
Mg, mg/L	<0.05
Na, mg/L	0.20
SO_4, mg/L	0.42
N, (NH_3) mg/L	0.05
NO_3, mg/L	0.16
Acidity Strong, meq/L	0.016
Acidity Weak, meq/L	0.015
pH	5.14

Figure 3.17 A weak low system to the northwest resulted in this trajectory from the southwest to the Kane Lake site. The initiation time was 8/04/00Z.

Date	7/23/82
Rainfall, mm	4.3
Ca, mg/L	0.19
Cl, mg/L	0.15
K, mg/L	<0.20
Mg, mg/L	<0.05
Na, mg/L	<0.20
SO_4, mg/L	0.22
N, (NH_3) mg/L	0.04
NO_3, mg/L	0.62
Acidity Strong, meq/L	0.021
Acidity Weak, meq/L	0.018
pH	4.83

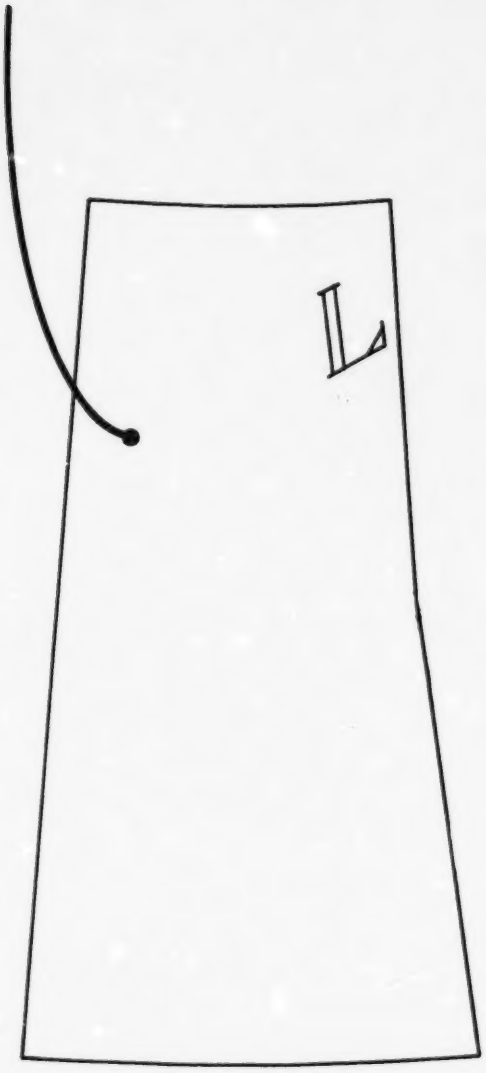


Figure 3.18 A low centre in the eastern part of Northern Saskatchewan resulted in this trajectory from the north into Cluff Lake. The trajectory initiation time was 07/23/18Z.

Date	9/2/82
Rainfall, mm	0.6
Ca, mg/L	<0.05
Cl, mg/L	0.10
K, mg/L	<0.2
Mg, mg/L	<0.05
Na, mg/L	<0.2
SO_4, mg/L	<0.05
N, (NH_3) mg/L	<0.04
NO_3, mg/L	0.07
Acidity Strong, meq/L	0.049
Acidity Weak, meq/L	0.021
pH	4.94

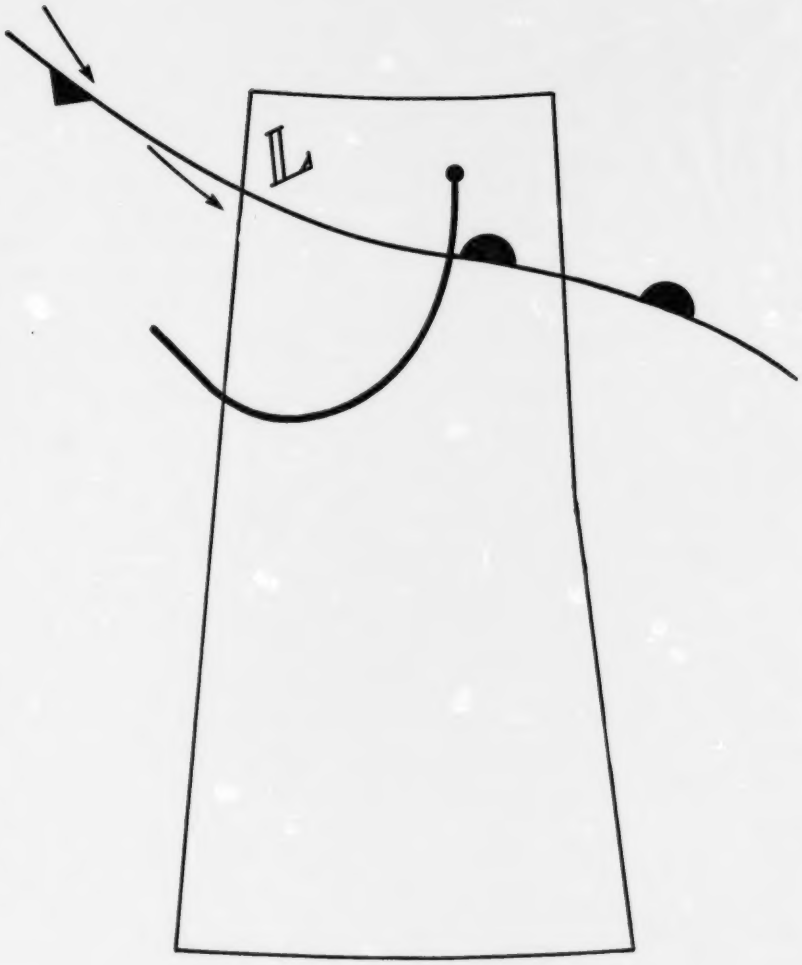


Figure 3.19 A low system in the northwestern part of the province resulted in the trajectory from the south into Stony Rapids. The initiation time was 9/3/06Z.

A summary of all of the trajectories for the year 1983 is provided in Table 3.2.

Table 3.2. The Average Chemistry (1983) Parameter for Trajectories Found in a Given Quadrant from the Site. Brackets Indicate the Standard Deviation.

a) Sulphate (mg/L)

	Lloyd	Dreaver	Kane
NW	0.78 (-)	0.85 (0.51)	0.43 (0.22)
NE	0.65 (-)	0.65 (1.28)	0.27 (0.21)
SE	-	1.26 (1.54)	0.83 (0.79)
SW	1.3 (-)	0.38 (0.18)	0.69 (0.48)

b) Nitrate (mg/L)

	Lloyd	Dreaver	Kane
NW	0.67 (-)	0.082 (0.106)	0.07 (0.007)
NE	0.096 (0.116)	0.101 (0.167)	0.116 (0.208)
SE	0.059 (-)	0.060 (0.037)	0.066 (0.037)
SW	0.162 (-)	0.074 (0.057)	0.160 (0.060)

The trajectories were classified into four quadrants about the respective site and the chemistry of the trajectory was assigned to that particular quadrant. The mean values of sulphate and nitrate are shown. Typically the southern quadrants trajectories had the highest values for sulphate. The southeast quadrant at Dreaver Lake for sulphate and the southwest quadrant for nitrate at the Lloyd Lake and Kane

Lake site had the highest values. Nitrate concentrations were high for the northeast quadrant of both Dreaver and Kane Lake sites.

3.2 Forest Fire Influence

The occurrence of forest fires was studied with regard to a swath defined by the trajectories. The forest fire influence was quite variable and dependent upon the site. Table 3.3 indicates the frequency of forest fires along the trajectories. It is seen that the occurrence of forest fires dominants at Lloyd Lake. At Kane Lake approximately one-half of the precipitation events have been influenced by forest fires for both years of this study. The rain at Dreaver Lake, Cluff Lake and Stony Rapids has been only slightly influenced by the forest fires.

Table 3.3 Frequency of Forest Fires (> 100 ha) along the rain trajectories.

a) 1983 Rain Trajectories

Site	Fires	No Fires	Total
Lloyd Lake	5	3	8
Stony Rapids	0	2	2
Cluff Lake	5	0	5
Dreaver Lake	8	31	39
Kane Lake	10	10	20

b) 1982 Rain Trajectories

Site	Fires	No Fires	Total
Cluff Lake	1	6	7
Dreaver Lake	4	15	19
Kane Lake	4	4	8

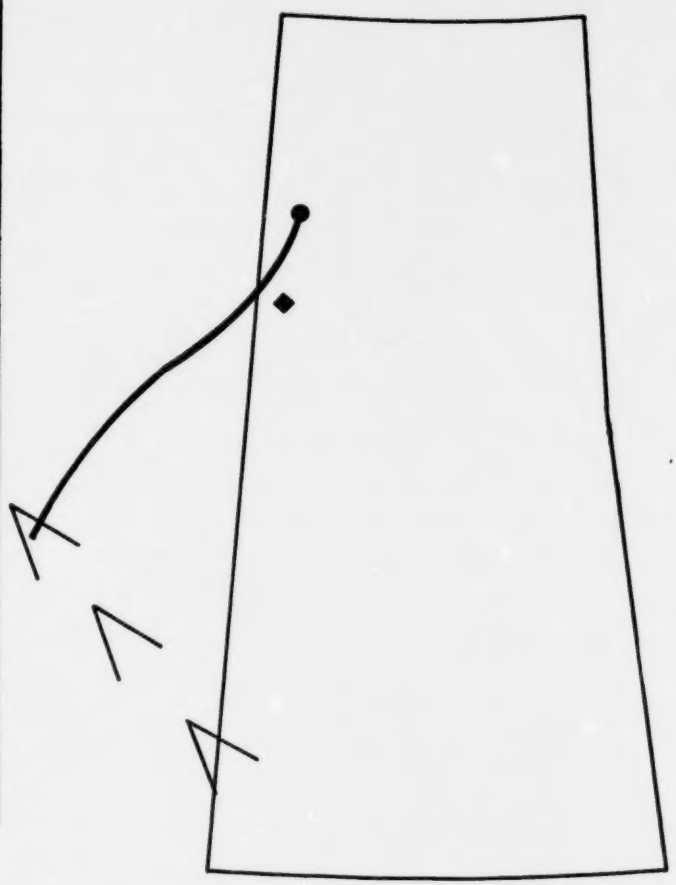
The volume weight mean chemistry parameters for pH, sulphate and nitrate at Lloyd Lake and Kane Lake are shown in Table 3.4. It is seen that in both cases there are significant increases in the acidity and nitrate concentrations while sulphate is not affected.

Table 3.4. Volume Weighted Mean Rainfall Concentrations of Various Chemical Parameters at Lloyd Lake and Kane Lake (1983) During the "Fires" and "No Fires" Influence on Trajectories.

Site	pH		SO_4 (mg/L)		NO_3 (mg/L)	
	Fire	No Fires	Fires	No Fires	Fires	No Fires
Lloyd Lake	5.6	6.0	0.9	1.4	0.150	0.055
Kane Lake	4.9	5.5	0.45	0.51	0.088	0.043

The direct impact of forest fires on the precipitation trajectories is shown in Figure 3.20. The rain was caused by a trowal from a weak cyclonic system passing to the south. The forest fire was located directly south of Lloyd Lake. The sulphate in the rain was 1.1 mg/L and the nitrate in the rain was 0.29 mg/L. The pH value was slightly acidic at 5.35. On 7/23/82 forest fires were quite near the Dreaver Lake site (Figure 3.21) during the rain occurrence. The nitrate value was 0.81 mg/L and the pH is 4.92. These values were considerably higher than normal at this location. Figure 3.22 shows several fires burning near the Kane Lake site at 7/26/83. The precipitation is originating from an upper level trowal with the cyclonic centre passing to the south. While sulphate does not appear to be elevated at 0.23 mg/L the nitrate does appear to be elevated at 0.19 mg/L, resulting in rain that can be considered acidic at 4.95. Acid precipitation was also noted at Cluff Lake

Date	06/28/83
Rainfall, mm	12
Ca, mg/L	0.64
Cl, mg/L	0.053
K, mg/L	<0.2
Mg, mg/L	0.05
Na, mg/L	<0.20
SO_4, mg/L	1.1
N, (NH_3) mg/L	0.13
NO_3, mg/L	0.29
Acidity Strong, meq/L	0.010
Acidity Weak, meq/L	0.020
pH	5.35

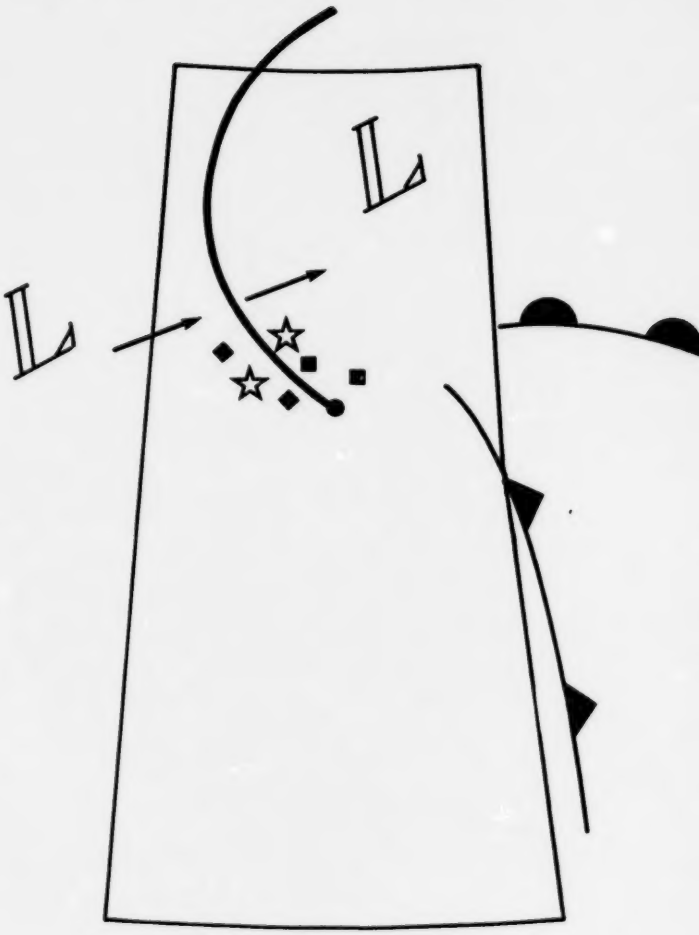


Fire Area Legend

Symbol	Fire Area (hectares)
☆	100 - 500
▲	500 - 1000
■	1000 - 2000
◆	2000

Figure 3.20 A trajectory that likely was influenced by forest fires occurrence at Lloyd Lake (1983). The rain resulted from a trowal from a low system far to the south. Trajectory initiation time was 6/28/00Z.

Date	07/23/82
Rainfall, mm	7.5
Ca, mg/L	0.45
Cl, mg/L	0.08
K, mg/L	<0.2
Mg, mg/L	0.50
Na, mg/L	0.30
SO_4, mg/L	0.72
N, (NH_3) mg/L	0.13
NO_3, mg/L	0.81
Acidity Strong, meq/L	0.016
Acidity Weak, meq/L	0.013
pH	4.92



Fire Area Legend

Symbol	Fire Area (hectares)
☆	100 - 500
▲	500 - 1000
■	1000 - 2000
◆	2000

Figure 3.21 A trajectory that was influenced by forest fire occurred at Dreaver Lake (1982). The rain is originating from a strong occluding low passing north of the station. Trajectory was initiated at 7/23/12Z.

Date	07/26/83
Rainfall, mm	5.0
Ca, mg/L	0.23
Cl, mg/L	0.29
K, mg/L	<0.2
Mg, mg/L	<0.05
Na, mg/L	<0.20
SO_4, mg/L	0.23
N, (NH_3) mg/L	0.19
NO_3, mg/L	0.19
Acidity Strong, meq/L	0.010
Acidity Weak, meq/L	0.027
pH	4.95

Fire Area Legend

Symbol	Fire Area (hectares)
☆	100 - 500
▲	500 - 1000
■	1000 - 2000
◆	2000

Figure 3.22 Kane Lake (1983) precipitation sample was likely influenced by forest fires within a short distance from the site. The rain was originating for an upper level trowal passing through the area. The trajectory was initiated at 07/27/06Z.

Date	08/06/82
Rainfall, mm	14.0
Ca, mg/L	0.19
Cl, mg/L	0.30
K, mg/L	<0.2
Mg, mg/L	<0.05
Na, mg/L	<0.20
SO_4, mg/L	0.99
N, (NH_3) mg/L	0.10
NO_3, mg/L	0.41
Acidity Strong, meq/L	0.026
Acidity Weak, meq/L	0.019
pH	4.59

Fire Area Legend

Symbol	Fire Area (hectares)
☆	100 - 500
▲	500 - 1000
■	1000 - 2000
◆	2000

Figure 3.23 A trajectory that was influenced by forest fires at Cluff Lake (1982). The rain was originating from an occluding low off to the northwest. Trajectory initiation time was 8/7/00Z.

(1982) in the presence of forest fires as seen in Figure 3.23. The forest fire source appears to be approximately 100 km to the south.

3.3 Wet Deposition

The values of wet deposition were obtained for each site by calculating the product of the ion concentration and amount of rainfall for each individual event. A sample calculation is shown in the Appendix B for Dreaver Lake and Kane Lake 1983. Adding the rainfall events through the entire period together provides the total wet deposition. It is clearly seen that an adequate study requires that every rainfall occurrence be monitored. If events are missed during the course of a year then the missing amount of precipitation can only be estimated by comparing to the regional rainfall reporting stations, or by adapting some form of completeness analysis to fill in the data gaps. Tables 3.5 and 3.6 show the actual amount of deposition of calcium, sulphate and nitrate determined from the summertime rainfall networks in Northern Saskatchewan for 1983 and 1982 respectively. After allowing for some obviously contaminated samples (i.e. visible pine needles or dirt noted in the sample by the observer or the analytical laboratory), the tables were constructed from the actual data presented. The deposition represents values only for the period of rainfall observation (i.e. May to October). The precipitation-weighted mean concentration is an important number as it is typical of rainfall events at the site. It was obtained by normalizing the deposition to the measured amount. This was calculated for calcium, sulphate and nitrate. The volume weighted pH for Kane Lake 1983 was calculated to be 5.16 (Appendix B). It tends to be quite low because pH is a logarithmic scale, One pH unit corresponds to

Table 3.5 Wet Deposition and Weighted Concentration for 1983 During the Observation Period.

Site	Measured Amount (mm)	Deposition	Weighted Concentration (mg/L)
Cluff Lake	26.1	0.07 kg (Ca)/ha	0.25 mg/L
		0.12 kg (SO_4)/ha	0.47 mg/L
		0.01 kg (NO_3)/ha	0.04 mg/L
Lloyd Lake	43.8	0.15 kg (Ca)/ha	0.33 mg/L
		0.39 kg (SO_4)/ha	0.88 mg/L
		0.05 kg (NO_3)/ha	0.12 mg/L
Dreaver Lake	247.8	0.79 kg (Ca)/ha	0.32 mg/L
		1.55 kg (SO_4)/ha	0.63 mg/L
		0.28 kg (NO_3)/ha	0.11 mg/L
Kane Lake	302.5	0.41 kg (Ca)/ha	0.14 mg/L
		1.47 kg (SO_4)/ha	0.49 mg/L
		0.20 kg (NO_3)/ha	0.07 mg/L

Table 3.6. Wet Deposition and Weighted Concentration for 1982 During the Observation Period.

Site	Measured Amount (mm)	Deposition	Weighted Concentration (mg/L)
Cluff Lake	39.0	0.21 kg (Ca)/ha	0.53 mg/L
		0.21 kg (SO_4)/ha	0.54 mg/L
		0.27 kg (NO_3)/ha	0.71 mg/L
Dreaver Lake	101.9	0.26 kg (Ca)/ha	0.26 mg/L
		0.38 kg (SO_4)/ha	0.38 mg/L
		0.45 kg (NO_3)/ha	0.44 mg/L
Kane Lake	33.6	0.06 kg (Ca)/ha	0.19 mg/L
		0.15 kg (SO_4)/ha	0.46 mg/L
		0.12 kg (NO_3)/ha	0.37 mg/L
Stony Rapids	11.0	0.02 kg (Ca)/ha	0.21 mg/L
		0.04 kg (SO_4)/ha	0.33 mg/L
		0.03 kg (NO_3)/ha	0.26 mg/L

an order of magnitude change in hydrogen ion concentration. Therefore, the lower pH values have much higher hydrogen ion concentrations which tend to dominate the average. It is important to note that virtually all of the rain sites in Northern Saskatchewan have weighted hydrogen ion concentrations that are considerably acidic (<5.6). It is also seen that rainfall collection amounts were higher in 1983 than in 1982. This reflects a more efficient network in 1983 since 1982 was considered a start up year.

In order to standardize these data on an annual basis there must be some way of filling the data gaps with missing information. In this study it was done by normalizing all of the deposition data to the amount of precipitation at the Environment Canada sites at Cree Lake and Cluff Lake. The precipitation data from the Cree Lake and Cluff Lake sites are shown in Table 3.7. The Cree Lake amounts were used to calculate annual deposition at Dreaver and Kane Lakes. The Cluff Lake amounts were used to calculate deposition amounts at Lloyd Lake, Cluff Lake and Stony Rapids.

Table 3.7 Precipiation amounts from the Environment Canada stations at Cree Lake and Cluff Lake.

a) Cree Lake.

	Rain (mm)	Snow (cm)
1983	302.3	135.3
1982	366.6	224.2

b) Cluff Lake Precipitation Amounts

	Rain (mm)	Snow (cm)
1983	267.2	108.5
1982	233.2	145.7

Table 3.8 shows the total estimated annual wet deposition at each of the indicated sites. Not all sites were in operation for the years of the study as indicated by the missing data. The rain deposition was calculated by normalizing the amount of measured rainfall to the amount of rainfall at Cree Lake (i.e.; the Dreaver Lake rain wet deposition was normalized to 302.3 mm rain for 1983) or Cluff Lake. The wet deposition as snow at each site was calculated by referring to the work of Shewchuk (1983), whereby the chemistry of the snow was determined for the specific area of the province. The amount of snow precipitation at each site was again taken to be that at Cree Lake or Cluff Lake. The rain deposition was linearly added to the snow deposition to give the best estimate of total deposition for the area. Wet deposition from the rain was in general much higher than that from snow in all cases. The wet deposition for Dreaver Lake and Kane Lake was not altered much from the previous tables. This was because the amounts of precipitation collected at these locations was nearly equal to those at Cree Lake. At other sites many events were missed. Essentially it is assummed for the purpose of this report that most of the sites have "under-caught" the

Table 3.8 Total Annual Wet Deposition of Sulphur from Rain and Snow at the Indicated Sites in Northern Saskatchewan in kg(S)/ha.

	1983			1982		
	Rain	Snow	Total	Rain	Snow	Total
Dreaver Lake	0.63	0.24	0.87	0.30	0.33	0.62
Kane Lake	0.49	0.24	0.67	0.56	0.37	0.93
Lloyd Lake	0.88	0.24	0.74	-	-	-
Cluff Lake	0.42	0.20	0.62	0.42	0.33	0.75
Stony Rapids	-	-	-	0.4	0.29	0.69

total amount of precipitation. The most consistent estimates of deposition came from Dreaver and Kane Lakes where many samples were collected. At Stony Rapids the data were scanty and this reflected in the quality of the deposition estimates. The total wet deposition of sulphur to the project area of Northern Saskatchewan is estimated to be less than 1 kg(S)/ha per year.

3.4 Ion Balance

A summary of the ion balances for the main locations of 1982 is shown in Table 3.9. Specific events thought typical are presented here. The hydrogen ion concentrations are reported as the strong acidity taken from the measured pH. In most of the samples collected, the hydrogen ion is the major cation. Other major cations were calcium and sodium. The anions were sulphate, nitrate, and occasionally chloride. The dominant anion usually was either the sulphate or nitrate one. It should be noted that the cations and anions do not balance, in general. A large number of samples from 1982 and 1983 have shown a major anion

deficit. There is likely an ion or group of ions that is not being measured. It was noted that the bicarbonate ion was missing from this data set. Previous studies for snow (Shewchuk, 1983) have shown the bicarbonate ion was normally quite low. Nevertheless its influence was present in most cases.

Table 3.9 Typical Rainwater Ion Balances from the 1982 network. All Units are in Microequivalents per Litre.

a) Cation Date	Cluff Lake July 22	Dreaver August 28-29	Kane August 3	Stony Rapids August 17
H	15	5	7	11
NH_3	2	12	4	6
Ca	10	18	9	13
K	<2	<3	<3	<3
Mg	<3	<3	<3	<3
Na	8	9	9	17
Total	41	50	35	47
b) Anion				
SO_4	5	12	9	8
NO_3	10	12	3	6
Cl	4	8	3	3
Total	19	32	15	17

A diagram showing the relation of the sulphate ion concentration in a solution to the hydrogen ion concentration is outlined in Figure 3.24. The purpose of this figure is to correlate the acidity of the sample with the sulphate ion. If the sulphate concentration in the rain

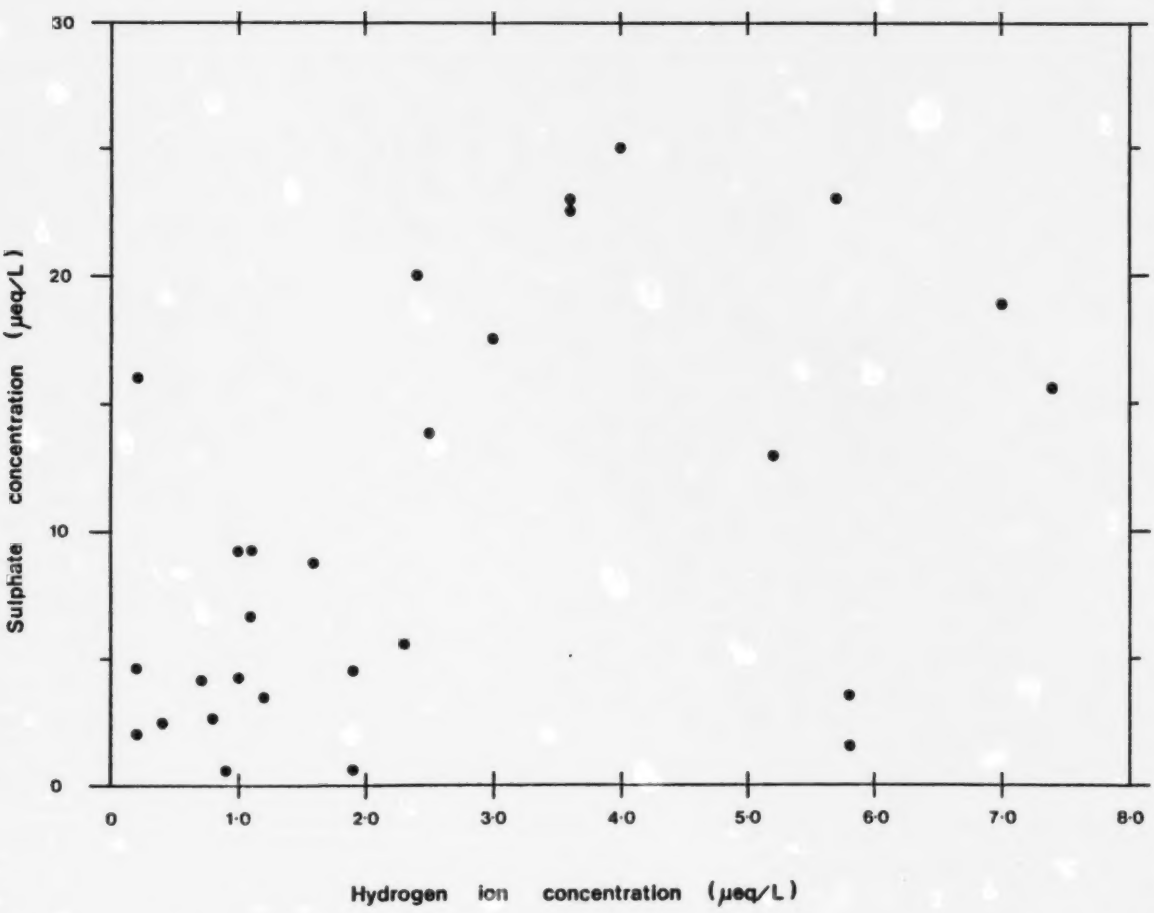


Figure 3.24 The relation of the hydrogen ion to sulphate ion concentration in the precipitation at Dreaver Lake (1983).

water is highly correlated with the hydrogen ion concentration, then the implication is that the hydrogen ion and the sulphate ion are linked through a common compound (in this case sulphuric acid). If there is no correlation between the sulphate and the hydrogen ion concentrations in the rain water then the two ions are not linked in a compound. Since there is no correlation Figure 3.2 implies that the majority of the sulphate ion likely originates from various compounds including neutral salts such as calcium or magnesium sulphate.

3.5 An Acid Deposition Scenario for Freshwater Precambrian Lakes

In an attempt to get an estimate of lake acidification potential in Northern Saskatchewan it will be useful to return to the nomograph of Liaw (1981). This depicts the rate of acidification of a typical Northern Saskatchewan lake, given the mean depth, alkalinity and an assumed rate of sulphur deposition. Mean depth was important in this consideration because it was directly related to water volume. The water volume is an important parameter to consider since it relates to the total time required to acidify the system, given a fixed deposition rate.

If one assumes that the deposition of sulphur in Northern Saskatchewan were to increase from its present value to 4 kg(S)/ha per year then the nomograph as shown in Figure 3.25 (from Liaw, 1981) can be applied.

The nomograph predicts the pH of lakes in Northern Saskatchewan based on the calcium and magnesium expressed as a bicarbonate. The nomograph shows the expected amount of time under varying buffering

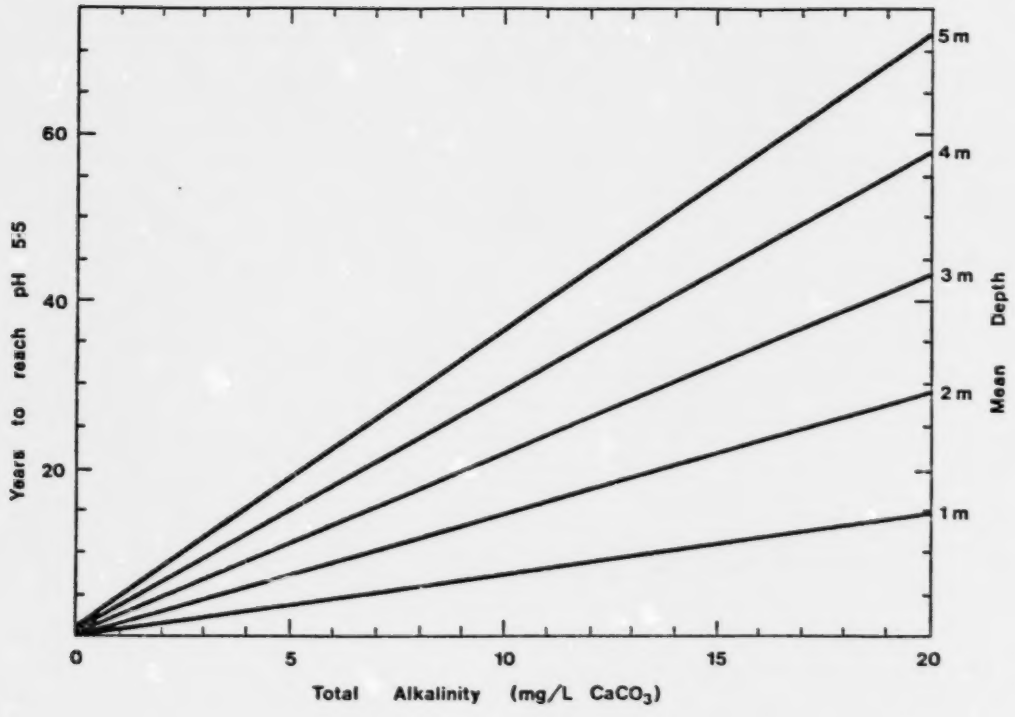


Figure 3.25 Nomograph from Liaw (1981) showing the expected rate of acidification of lakes in Northern Saskatchewan to pH 5.5 under various buffering capacities and an atmospheric sulphur deposition rate of 4.0 kg(S)/ha per year.

capacity conditions for lakes to pH 5.5. The lake is acidified at this value. The time to acidify a small lake of alkalinity 10 mg/L and depth 2 metres would be 15 years. Thus this Figure indicates that with increased acid deposition in Northern Saskatchewan, the shallow and poorly buffered Precambrian Shield lakes may be acidified within one or two decades. However, as pointed out by Liaw (1981) many factors are involved in determining the rate of acidification in lakes. These predicted rates of lake acidification must be considered with great care. The scenario presented here can be considered only as a first approximation.

4.0 CONCLUSIONS AND DISCUSSION

4.1 Trajectories

The rain samples from both years of this study have shown that the precipitation in Northern Saskatchewan is a dilute solution of several inorganic ion species. The trajectories, while they are qualitative indicators of air mass past history during the precipitation, were quite useful in that they showed air flows from the south contaminated the precipitation more than air flows from the north. The assumption that surface geostrophic winds reflect the mean mixed layer motion within the planetary boundary layer was acceptable for this study. While major precipitation systems are not present within the boundary layer, their updrafts and downdrafts provide a direct link with this mixed layer. Thus it is entirely possible for a mesoscale system to have winds at the top of the mixed layer that represents the air pollutant transport winds. For example, intense storms originating in the southeast sector and passing over the site at Dreaver Lake show the highest sulphate acidities. This implies that there may be a relationship between the acidity of the rain and the air mass passing near anthropogenic emitters of sulphur dioxide. However, such a conclusion needs verification.

The quality of the rain does reflect to some extent the source region of the air mass. The northerly sectors at each of the sites are covered with Precambrian rock and lakes. This provides little opportunity for the air mass to be contaminated with surface suspendable material. When trajectories, which originate from the south, pass near industrial and alkaline earth sources (farm lands) the rainfall is contaminated with high concentrations of major ions. In several cases

significantly elevated mineral acidity levels at some of the sites can be directly traced back to an anthropogenic origin.

It seems that trajectories lying in some quadrants were more contaminated than others. The standard deviations from the samples show, however, that the spread in variance is so large that it is not possible to say one quadrant is any higher in concentration than any other. Each quadrant may contain a mixture of contaminated and uncontaminated trajectories from a given sector. Consequently, a rather large variance should be expected. It is quite interesting to note that, in general, if the quadrant-derived sulphate concentration was low, the standard deviation was also low, but if the quadrant-derived sulphate was high then the standard deviation was also high.

The effect of forest fires on the quality of the precipitation was significant. Not only did the acidity increase but the nitrate concentration was shown to increase correspondingly. Forest fires emit large amounts of particulates into the atmosphere which can act as nuclei for cloud droplets or be scavenged by larger particles. Not all sites in the area were affected by forest fires to the same extent. If the influence of forest fires is to be shown at a particular site, a high quality data base must exist.

4.2 Wet Deposition

The regional deposition of sulphur has been estimated at all sites in the area of Northern Saskatchewan for the years 1983 and 1982. Values of total sulphur wet deposition are in the order of 1 kg/ha per year for rain and snow. Low precipitation pH values continue to support the premise that Northern Saskatchewan is receiving some form of

acid precipitation. The origin of the acidity remains uncertain at the present time; however, with the low sulphur deposition amounts, natural acidity sources cannot be discounted.

The precipitation chemistry classification of air mass back-trajectories, particularly at Dreaver Lake, tends to support the concept that the wet deposition is not completely influenced by natural causes. From a natural system one would expect a fairly uniform distribution of quality within each quadrant. The precipitation weighted mean sulphate deposition for Northern Saskatchewan was given by Bangay and Riordan (1983) as 1.6 kg(S)/ha per year for 1980. This value is marginally higher that the estimates from this work. In general the data of this report do agree quite well with Environment Canada data. In fact there is remarkably good agreement with the values generated by Kociuba et al., 1984 for the Cree Lake area (1.25 kg(S)/ha).

4.3 Ion Balance

There was uncertainty in measurement of the ion concentrations associated with this type of analysis since in most cases the work was conducted at the detection limit for most of the analytes. In addition, even though careful methods were employed, it is often possible to contaminate an environmental sample, either through handling and preservation or in the analytical laboratory. In general, the major ion balances of the precipitation from this project indicated that there was a cation imbalance with either the hydrogen ion (as acidity) or the calcium ion dominating the balance. Attempts to correlate the sulphur and nitrogen in solution to the acidity were not successful. This indicates that a possible source of acidity at present is not a mineral acid.

There can be several other causes for the lack of definition of the hydrogen ion, such as, electrode polarization at dilute solutions, streaming potentials during the measurement or organic acids. Much work has been conducted on acidity determinations on rain and snow in Northern Saskatchewan (Shewchuk, 1983) and it is seen that by using titrations we can measure approximately 30 microequivalents per litre of total acid in a majority of the snow samples from this area. Approximately one half of this acidity is from a strong acid, it represents pH values in the range 4.8 to 5.4. In southern Ontario, Bangay and Riondan report the (1983) deposition of strong acid averages approximately 25 to 100 microequivalents per litre. This represents a pH range of approximately 4.1 to 4.6. The origin of strong acid in the precipitation samples of northern Saskatchewan is at present unknown. However, strong acid deposition to the environment is significantly less than in areas of North America known to have acid deposition impacts.

4.4 Sensitivity Appraisal

The present low alkalinities and pH of most of Northern Saskatchewan lakes is a reflection of the geochemical and soil conditions of their watersheds. If a lake and its watershed contain little buffering capacity, even clean rain (pH <5.6) can act in the long term to gradually consume the alkalinity and then reduce the pH of the water. There is of course a natural equilibrium situation that may be established whereby input acidity and alkalinity may be nearly balanced.

The primary buffering of an aquatic system is provided by the bicarbonate content. Alkalinity is used to indicate the bicarbonate buffering capacity. Since the buffering capacity of the area is quite

low, there is reason to believe that, with the onset of higher rates of deposition from the present value, many of Saskatchewan's small Precambrian Shield lakes could be acidified in a rather short time frame. Lakes similar to these in Ontario have been acidified in approximately two decades (Conroy et al., 1978).

Since there is clearly a link between air mass dynamics and deposition of acids, environment protection used in future studies should deal correctly with the atmospheric phases of pollutant cycles. It is therefore necessary to take into account the meteorology involved in the mescoscale (<500 km) transport of pollutants as has been done in this study.

5. RECOMMENDATIONS

5.1 Origin of Strong Acidity

The rain in northern Saskatchewan is a rather dilute solution of various inorganic ions including calcium, magnesium, chloride, ammonium, sulphate, nitrate and hydrogen ions. There is also little resident alkalinity available in the rain to buffer an influx of anthropogenic acidity. The dilute nature of the precipitation makes it quite difficult to establish a meaningful precipitation data base, because in most cases the ion concentrations are at the detection limit of the analytical methods. In addition, it is difficult to avoid sample contamination through handling and other means. In summary, the source of the acidity in the rain is not well parameterized. It is recommended that a detailed project be undertaken to determine the nature of acidity observed in the rain samples. An area of further study should involve the analysis of the rain samples for organic acids.

5.2 Wet Deposition Measurements

There is a direct link between emissions in Western Canada and deposition in this area. It has been demonstrated that wet deposition through rainfall is one of the prime ways in which acid deposition is reaching the environment and wet deposition can be measured relatively easily. It is recommended that the monitoring aspect of this program continue until a consistent and meaningful data base has been established. Once an acceptable data base has been established it is suggested that the project be downscaled and conducted at only two sites for the long term.

5.3 Trajectories

The trajectory classifications have proven to be a useful means of identifying source region influences. The groupings of the trajectories into the various quadrants indicated that there was indeed a difference in the mean quality of the chemistry from one region to another. Air mass trajectories from the south were higher in concentration of most ion species than those from the north. It seems clear that if the precipitation regime at one site near a regional emitter impacts on that site through LRTAP, then the chemistry at that site is going to be a combination of anthropogenic effects (i.e., high values) and natural effects (i.e. low values). The mean value of these influences is quite likely to be a number with a large standard deviation as seen in this data set. A longer period of record will allow a more accurate description of the variation.

In addition, forest fires do have an influence. Back trajectories are an effective way to classify forest fires. The influence of forest fires on the trajectories at Lloyd Lake and Kane Lake seems to be quite definitive. Elevated levels of both acidity and nitrates are clear indicators of forest fire effects (Darley et al., 1973). While air mass back trajectories cannot explain all of the variability of the rainfall chemistry, they can assist in an interpretation. It is recommended the air mass back trajectories continue to be used as a tool to further develop an understanding of the air mass history prior to the occurrence of a rainfall event. This will assist in intrepretation of the precipitation chemistry results.

5.4 Precipitation Amounts

Determination of the quantity of rainfall is just as important as determination of the rainfall quality (i.e., ion chemistry). There are many climatological techniques that can be applied to the region at the selected sites in Northern Saskatchewan to improve the climate data base. Procedures similar to those outlined by Wheaton (1979) can be applied directly to the project area. Here the evaluation of the climate of a large area with few reporting stations requires a special approach. It is recommended that an improvement in rainfall measurement techniques be considered for the region of Northern Saskatchewan and that a correlation analysis, point distribution coefficient and the spatial pattern of the completeness index be employed for evaluation of rainfall distribution amounts. Such a study will complement the rainfall chemistry programs and allow the best possible estimate of total wet deposition on a regional basis.

5.5 Collection Procedures

The network established at Lloyd Lake, Stony Rapids, Kane Lake, Dreaver Lake and Cree Lake (1984) does represent an acceptable regional network for the study of acid deposition. It is important now to improve the quality of the collection of rain at some of the stations. It is desirable to have the field observers collect as much of the precipitation as possible so that the least amount of interpolation is required for a deposition estimate. If some sites are clearly having difficulty collecting all the rainfall, it is suggested that the automatic rain gauge as described in Shewchuk and Abouguendia 1985 be used. This gauge remains entirely unattended until "after-the-fact". It puts

much less burden on the field observer. It has a wide collection surface area and there is virtually no field sample handling required.

There has been an indication that some of the frozen bags of precipitation in the study have been thawing and some have been leaking prior to arrival at the analytical laboratory (Yuen, 1985). It is suggested that every effort be made to have the sample arrive at the analytical laboratory with its integrity at the highest possible level. This reduces the chance of sample contamination and provides a consistent data set. Certainly the samples from the entire network should be frozen; if this is not possible then the specific differences should be noted. There should be periodic system checks to ensure that the network quality is consistent. Field observers should open the bucket immediately at the beginning of the rain and collect the sample at the end of the event. It is recommended that the bags be changed daily, if possible, even though no rain has occurred.

In order to document intra-site variability it is useful to operate the system with two identical collectors at one site. No mixing of the collected precipitation samples would be allowed. This would help determine the limits of error to assign to the chemistry at a single site.

It is suggested that studies be undertaken to confirm the lack of resident acidity in the bags used to collect the rain. It is likely that inorganic ions are completely absent but it would be worthwhile demonstrating this with each series of analysis. It would also be a useful addition to introduce the field blank concept to this program.

<u>It is recommended that the quality of the collection procedures be improved at several of the sites</u>.

5.6 Possible Increased Emissions Impact

One must take into account the strong connection between atmospheric pollution and mesoscale synoptic meteorology to effectively account for this aspect of medium range transport of air pollution. Wet deposition is an important mechanism of atmospheric acidification for Northern Saskatchewan. It is possible with a mesoscale modelling approach to estimate what type of emissions loading the environment in Northern Saskatchewan could support via a lowering of rainfall pH. This is so because of the rather dilute nature of the rainfall. Any increases in sulphur or nitrogen oxide emissions would increase the acidity of the rain due to its lack of buffering capacity. It is normally assumed that the one hundred percent of the sulphur is scavenged from the atmosphere in the presence of rain within several 100's of km of an emitter (Smith 1981, Chan et al., 1982). Therefore, if emissions should increase acid deposition should increase proportionately on the Precambrian Shield areas of the province. It is recommended that wet deposition air quality modelling be used to establish the relation between emissions increases and depositions increases particularly within a few hundred kilometres of major point sources.

In summary, Northern Saskatchewan (particularly the Precambrian Shield areas) is highly sensitive to acid deposition. Most of the area is receiving total wet deposition of sulphur in the order of 1 kg/ha per year. This value is quite near the lowest value recorded anywhere on earth. With the potential growth of major point source emitters of sulphur and nitrogen oxides within and near the Precambrian Shield, the increase of acid deposition from the current values is likely. Major atmospheric and total environment studies must continue if one is to

understand the extent of acid tolerance for this important area of Canada.

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APPENDIX A

RAIN SAMPLING SURVEY IN NORTHERN SASKATCHEWAN-PROCEDURES MANUAL AS PREPARED BY SASKATCHEWAN ENVIRONMENT

PRECIPITATION CHEMISTRY

PROCEDURES MANUAL

PRECIPITATION STUDY

NORTHERN SASKATCHEWAN

Prepared by

Saskatchewan Environment

THE STUDY NETWORK

Figure 1 is a map of the 8 sites where precipitation chemistry sampling instruments will be located. These 8 locations should well represent all of Northern Saskatchewan.

INSTRUMENTATION

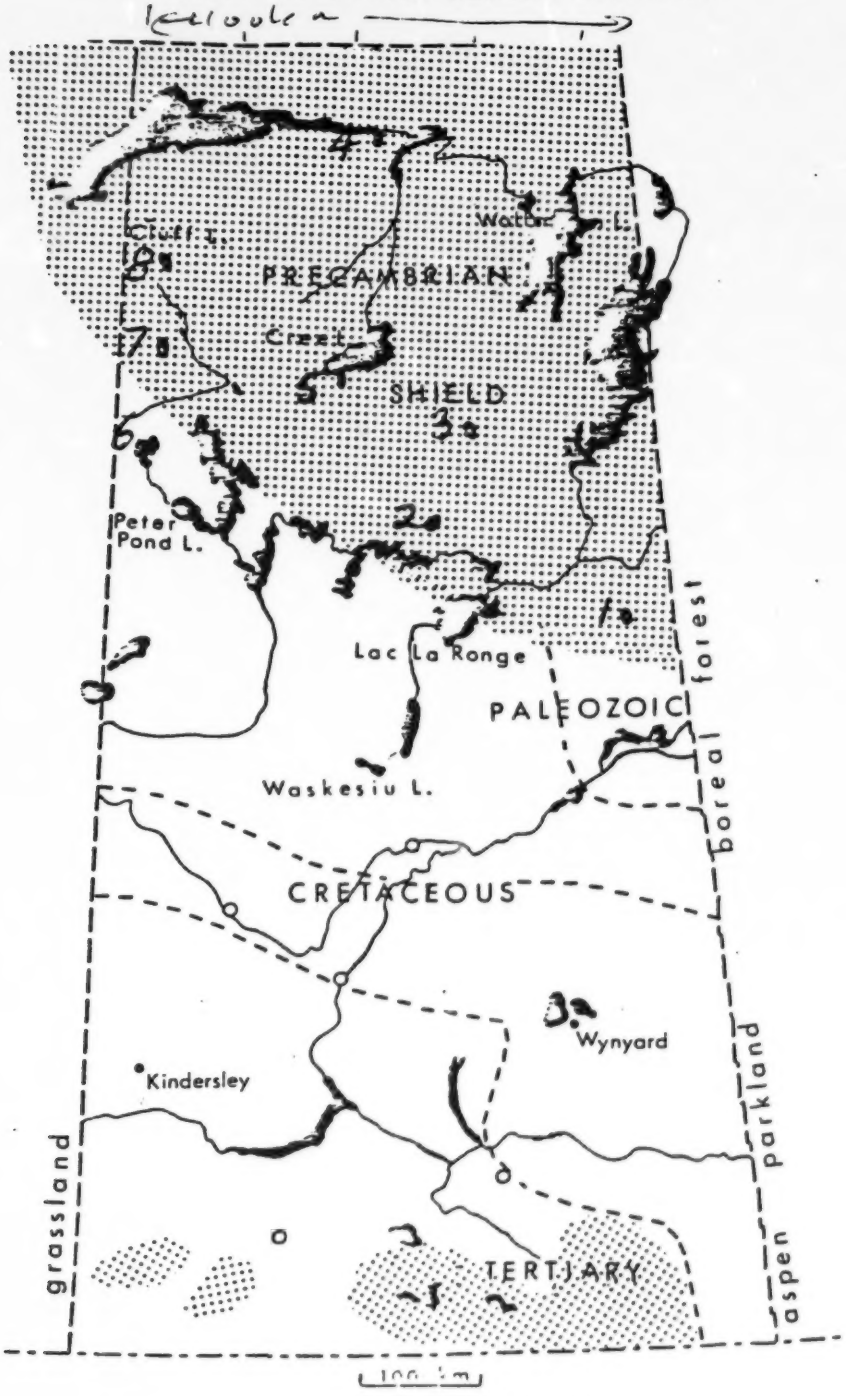
Event, wet-only sampling is the only form of precipitation collection employed during this study. This means that the precipitation from each individual storm is collected while that shower is in progress. Once the precipitation stops, the sample is collected.

The 1982 sampler design is illustrated in Figure 2. It consists of a 100 litre (22 imp. gal.) polyethylene container (commonly used as domestic refuse recepticals) with a tight-fitting lid to prevent all other materials from entering when the lid is on. Modified, plastic bags are used inside the container to collect the samples (Figure 3). The bags have a diagonal seam imprinted into them. The purpose of this is to reduce evaporative losses and to help prevent contamination of the sample.

The following is a list of equipment and supplies that each site will be issued for the collection of precipitation samples:

- plastic sampling container with sealing lid (1)
- stakes to secure sampler to ground (4)
- sample bags (50)
- black "garbage" bags (20)
- plastic bag heat-sealer (1)
- report sheets (20)
- box of disposable gloves (1)

SASKATCHEWAN RAIN SAMPLING LOCATIONS



STATION LOCATIONS

1. Pelican Narrows
2. Dreaver Lake
3. Kane Lake
4. Stony Rapids
5. Cree Lake
6. La Loche
7. Lloyd Lake
8. Cluff Lake

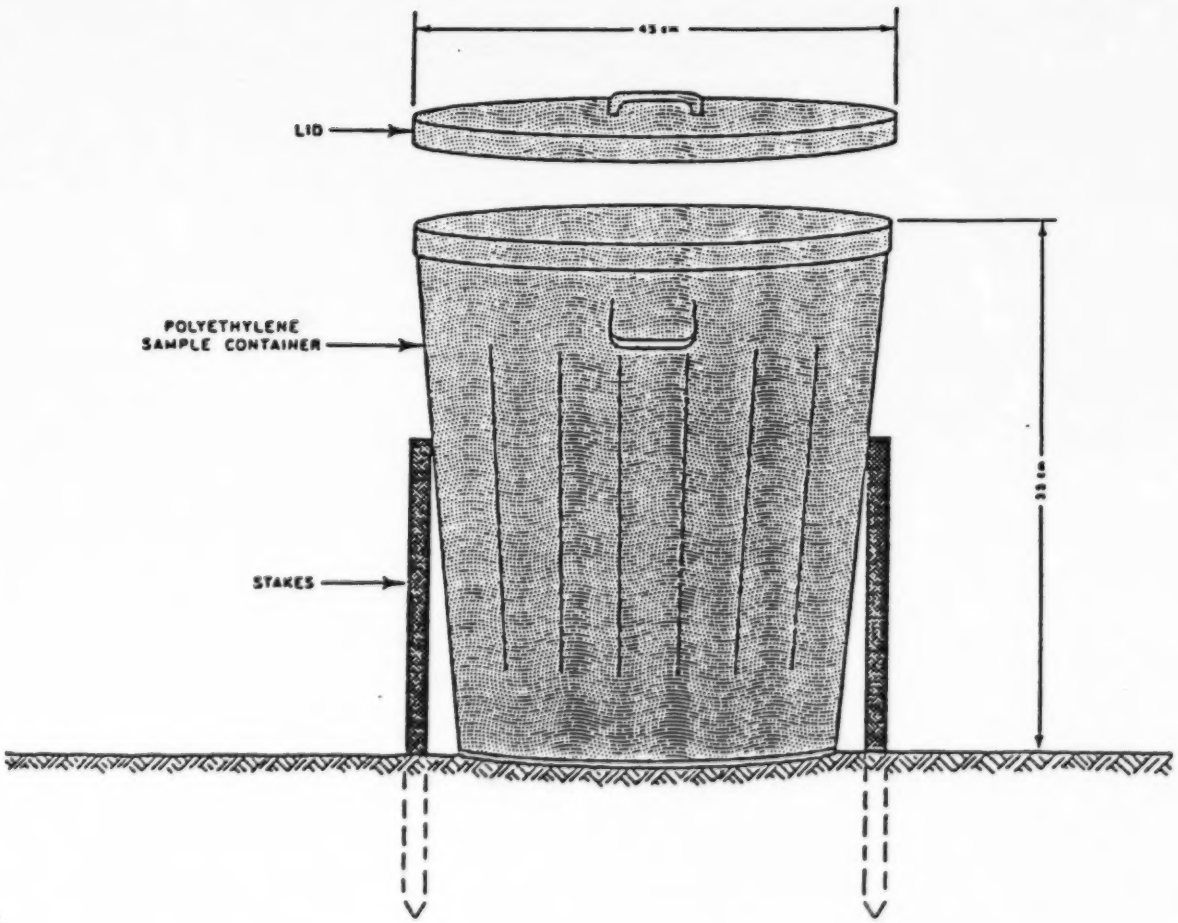


FIGURE 2 · 1981 SAMPLER · EVENT, WET-ONLY

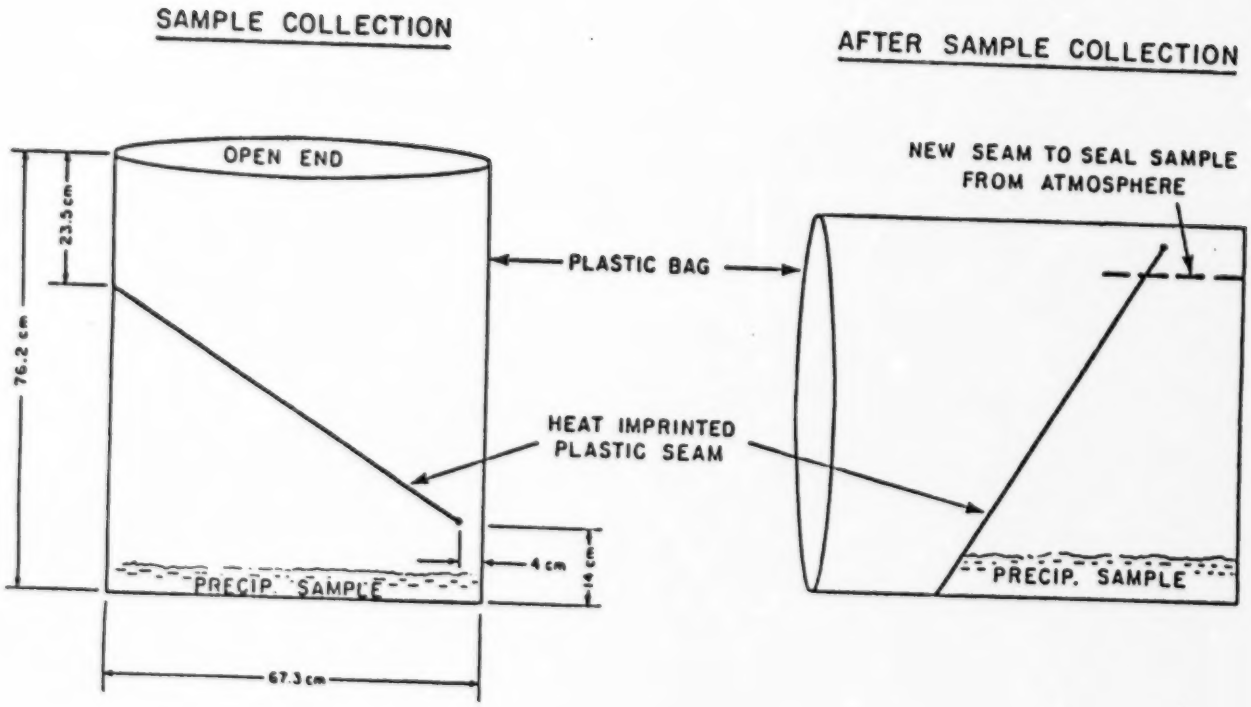


FIGURE 3 : SAMPLE COLLECTION BAGS

- tags for sample bags (20)
- box of kimwipes
- rain - gauge and stand (1)

(Set-up of the sampling containers and stakes will be done by Saskatchewan Environment in mid July, 1982).

SAMPLE HANDLING PROCEDURES

Sample handling is one area where contaminants can be introduced into the sample. The slightest mistake on the part of the person collecting the precipitation can ruin the entire sample. Such mistakes can occur in a matter of seconds--they are irreversible and result in bad data. Examples of contamination are:

- touching the collection surfaces;
- sticking a finger into the rain sample; and
- dropping things into the sample such as hair, dirt or grass.

When handling the samples, it is absolutely necessary to remember that there are a large number of ways to contaminate them, so always watch carefully that you are not causing contaminants to enter the sample. If one follows the procedures listed below, the samples should provide excellent data:

1) Installation of sample bag into the 100-litre container
   - put on disposable gloves. Take care not to touch the finger areas of the gloves. Try not to touch anything that can otherwise be avoided;
   - take out one sample bag. Do not touch the inside of it;
   - using your thumb and index finger, grasp the two corners of the opening of the sample bag. At the corner of the bag your thumb should be inside the bag and the index finger on the

outside. Roll the edge of the bag over so you have approximately 2 cm of edge.

- now take the bag and lower it into the garbage container and pull the edge of the sample bag over the edge of the container for a tight seal around the edge.
- some bunching of the sample bag inside the container might occur but do not touch the inside the bag.
- wipe off the lid with "Kimwipes" to ensure no contaminants are present on the lid.
- finally, replace the lid of the container and seal with the handles in the vertical position.

The container is now ready for rain sampling.

2) Rain Sampling Procedures

When the rain begins to fall:

- record time and date on both tag and report sheet.
- go out to sampler and remove lid.
- take lid back inside with you and place it in a clean dry place.

After the event is over, remove the sample bag by the following procedures:

-grasp the edges of the bag and lift it out of the container;

-close the opening of the bag and drain the precipitation into the bottom corner of the bag below the diagonal seal. Gather the bag just above the sample. Fold the bag over at the collection point and take a wire tag and wrap it around.

-once the sample is tied, cut off the extraneous sample bag.

-report the time that the rain event ended and the other information that is required on the report sheet and the tag.

-seal the bag (see Figure 3) with the heat-sealer:

--after cutting, place the narrow portion of the bag in the heat-sealer. Make sure the seal will cross the diagonal seam and the bottom edge. Press the sealer down for approximately 10 seconds. Make sure the seal is secure by turning the bag upside down and looking for leaks. If there are leaks, re-seal the bag.

-put the sample into the black plastic bag and place it in the refrigerator.

Sampling and recording of information is now complete.

NOTE: Duration of rain events vary throughout the season. These guidelines should be followed for collecting samples:

1. If the rain event only lasts a short time then remove the sample as soon as the event is over.
2. If the rain event is a long one, replace the lid when a maximum of 12 hours is reached and remove the sample.
3. If a rain event is still taking place but you can no longer monitor the event (going to sleep, etc.), then take the sample instead of leaving it open for extended periods.

RAIN SAMPLE INFORMATION - 1982

STATION: _____

SAMPLE DATE: Day _____ Month _____

TIME OF SAMPLE: Start _____ End _____

WIND DIRECTION: Start _____ End _____

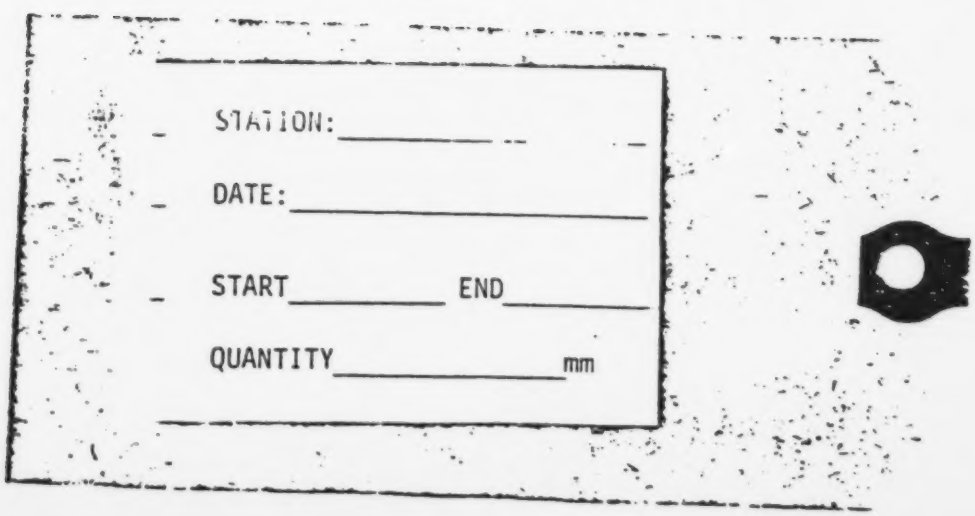
RAIN GAUGE: Start _____ End _____

TYPE OF EVENT:

1. Rainstorm
2. Thunderstorm
3. Showers
4. Drizzle
5. Snowstorm
6. Snow showers
7. Freezing rain or hail
8. Mixed rain and snow

COMMENTS:

1. Insect(s) in sample
2. Leaves in sample
3. Particles (sand, etc.) in sample
4. Fibres in sample
5. Other _____
6. Sample spilled
7. Part of event missed
8. All of event missed
9. Forest fire in area
10. Other _____



II. RECOMMENDATIONS

A. Siting Criteria

The siting criteria which follow are those recommended for monitoring on a regional spatial scale. A regional scale will usually define a rural area of reasonably homogenous geography and may extend from tens to hundreds of kilometers. Data characteristics of this scale provide information on larger scale processes of pollutant emissions, losses, and transport as they relate to precipitation chemistry. The site itself is chosen at a location (preferably a flat, open area) considered to be representative of the region.

(1) Within 50 km of the sampler there will be no anthropogenic emission sources which could affect precipitation chemistry. Sources greater than 50 km from the site are considered to exert a regional influence.

(2) Within 1.0 km of the sampler there will be (i) minimal and preferably no moving sources of pollution such as air, water and surface transportation, (ii) no surface storage sources of pollution such as sewage plants and (iii) no wind activated sources of pollution such as cultivated fields and areas of no vegetation.

(3) The distance between the sampler and nearby furnace or incinerator flues must be sufficient that emissions do not affect the chemistry of the collected sample. A horizontal separation between the flue exit and sampler of at least 100 meters is recommended.

(4) Within 5 meters of the sampler there shall be no object above the height of the sampler.

(5) No object shall be closer to the sampler than a distance of 2.5 times the height the object extends above the sampler.

(6) Sampler intake should be located 1-2 meters above height of existing ground cover.

The siting criteria identified above must be followed to the maximum extent possible to ensure uniform collection of data. It is recognized that there will be situations where these criteria cannot be followed in their entirety. In these cases a rationale for identifying unacceptable deviations from the criteria needs to be employed.

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APPENDIX B

WET DEPOSITION ANALYZED DATA (1983)

for

DREAVER LAKE AND KANE LAKE

DREAVER LAKE PRECIPITATION 1983

Deposition per Rainfall in kg/ha for Ca, SO4 and NO3.

EVENT	5-17	5-18	5-25/26	5-31	6-1	6-7	6-7
AMOUNT	3.5000	1.2000	8.0000	12.3000	12.5000	7.0000	2.8000
Ca DEP	0.0126	0.0107	0.0192	0.0357	0.0263	0.0112	0.0140
SO4 DEP	0.1050	0.0720	0.0160	0.1353	0.1138	0.0154	0.0288
NO3 DEP	0.0025	0.0480	0.0024	0.0135	0.0054	0.0036	0.0012

6-9	6-14	6-20	6-23	6-25	7-7	7-9
2.2000	8.9000	9.0000	1.2000	2.7000	5.8000	1.2000
0.0114	0.0205	0.0162	0.0055	0.0035	0.0110	0.0348
0.0097	0.0196	0.0058	0.0126	0.0051	0.0058	0.0528
0.0035	0.0044	0.0029	0.0009	0.0007	0.0026	0.0126

7-16	7-17	7-18	7-21	7-26	7-30	8-12
3.5000	2.4000	2.0000	26.6000	4.0000	2.3000	7.6000
0.0105	0.0070	0.0070	0.0239	0.0092	0.0122	0.0357
0.0042	0.0106	0.0064	0.1277	0.0136	0.0179	0.0912
0.0026	0.0013	0.0004	0.0059	0.0056	0.0010	0.0266

8-17	8-29	9-1-2	9-2-3	9-4	9-6	9-7
7.5000	0.7500	5.0000	3.5000	7.8000	1.2000	2.1000
0.0165	0.0233	0.0210	0.0046	0.0164	0.0092	0.0124
0.1275	0.0330	0.0850	0.0350	0.0484	0.0132	0.0176
0.0029	0.0038	0.0065	0.0013	0.0023	0.0007	0.0005

9-7	9-9-10	9-16	9-16-17	9-17	9-17-18	9-18
11.5000	5.8000	10.7500	11.0000	22.5000	10.0000	8.0000
0.0242	0.0145	0.1720	0.0198	0.0158	0.0130	0.0128
0.0311	0.0093	0.0720	0.0825	0.0450	0.0010	0.0096
0.0068	0.0012	0.0699	0.0083	0.0045	0.0013	0.0010

9-18-19	10-3-4	10-9-10
5.0000	4.2000	4.5000
0.0170	0.0164	0.0387
0.0010	0.0218	0.0495
0.0003	0.0020	0.0162

	TOTAL DEPOSITION		Weighted-Concentration	
	247.8000	mm		
Ca	0.7855	kg(Ca)/ha	Ca(mg/L)	0.32
SO4	1.5517	kg(SO4)/ha	SO4(mg/L)	0.63
NO3	0.2760	kg(NO3)/ha	NO3(mg/L)	0.11

KANE LAKE PRECIPITATION 1983

Deposition per Rainfall in kg/ha for Ca, SO4 and NO3.

EVENT	5-20	6-2	6-7	6-9/10	6-14	7-1	7-16
AMOUNT	1.00	40.00	5.00	1.50	22.00	5.00	15.00
Ca	0.0029	0.0720	0.0110	0.0030	0.0220	0.0170	0.0150
SO4	0.0210	0.4400	0.0230	0.0042	0.0528	0.0400	0.0300
NO3	0.0012	0.0224	0.0039	0.0007	0.0092	0.0050	0.0095

	7-18	7-22	7-26	7-28	8-3	8-16	8-20
	6.50	22.50	5.00	5.00	22.50	18.50	7.80
	0.0065	0.0203	0.0115	0.0085	0.0293	0.0796	0.0172
	0.0104	0.0248	0.0115	0.0100	0.0945	0.2035	0.0499
	0.0023	0.0074	0.0095	0.0055	0.0180	0.0407	0.0057

	8-21	9-2	9-6	9-16	9-18	9-19
	3.80	50.00	5.30	35.60	25.40	5.10
	0.0046	0.0350	0.0101	0.0214	0.0152	0.0066
	0.0122	0.3350	0.0292	0.0570	0.0203	0.0056
	0.0006	0.0230	0.0041	0.0107	0.0165	0.0010

TOTAL DEPOSITION

RAINFALL	302.50	mm
Ca	0.4085	kg(Ca)/ha
SO4	1.4748	kg(SO4)/ha
NO3	0.1970	kg(NO3)/ha

Weighted-Concentration

Ca(mg/L)	0.1350
SO4(mg/L)	0.4875
NO3(mg/L)	0.0651

KANE LAKE PRECIPITATION ACIDITY SUMMARY

EVENT	5-20	6-2	6-7	6-9/10	6-14	7-1	7-16
pH	4.40	5.58	5.85	5.12	5.08	4.42	4.99
MICRO H+	3.98E-05	2.63E-06	1.41E-06	7.59E-06	8.32E-06	3.80E-05	1.02E-05
H+*amount	3.98E-05	1.05E-04	7.06E-06	1.14E-05	1.83E-04	1.90E-04	1.53E-04

	7-18	7-22	7-26	7-28	8-3	8-16	8-20
	5.10	5.21	4.95	4.85	4.56	5.35	4.88
	7.94E-06	6.17E-06	1.12E-05	1.41E-05	2.75E-05	4.47E-06	1.32E-05
	5.16E-05	1.39E-04	5.61E-05	7.06E-05	6.20E-04	8.26E-05	1.03E-04

	8-21	9-2	9-6	9-16	9-18	9-19
	5.13	5.90	5.05	5.98	5.48	4.93
	7.41E-06	1.26E-06	8.91E-06	1.05E-06	3.31E-06	1.17E-05
	2.82E-06	6.29E-05	4.72E-05	3.73E-05	8.41E-05	5.99E-05

ACIDITIY SUMMARY AT KANE LAKE 1983

Total precip at Kane Lake 302.50 mm

precip weighted H+ 6.95E-06 eq/L
or
pH=5.16